BENCHMARKING AND IDENTIFICATION OF BEST PRACTICE ASSOCIATED WITH INDUSTRIAL WATER USE IN UK

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Abstract

In the wake of the phenomenal growth rate of fresh water use globally, the need to ensure security of supply and maintain optimal competiveness in water business has heralded the increasing awareness to measure and compare water use by means of meaningful metrics, performance indicators and benchmarks. Thus, in view of the historically intensive use of water by UK industry, this research set out to benchmark the sector's water use; the overarching aim being to deduce performance gaps in water use by industry, identify best-in-class practices associated with industrial water use, and proffer efficient improvement strategies for optimal performance in the sector.

To achieve this aim, and in line with the research funder's anticipated outcome of this study, a benchmarking software called *"i-Water Benchmarking Tool"* was developed. Although, few tools and methodologies are available for benchmarking performance with respect to water usage, but most of these tools are mainly domestic water use specific, developed by, and are within the ownership of commercial organizations. Hence, the *rationale* behind the software development is to provide a robust, user-friendly and accessible tool that can be used to benchmark water use across industrial subsectors and establish the basis for improvement in performance.

Based on the foregoing, comprehensive data were sourced from UK water undertakings, trade bodies and environmental agencies, and used to conduct statistical data analyses and performance benchmarking. Results of the analyses revealed that in England and Wales, from 2003 – 2013, *"Metals"* constituted the highest consumptive water user (43% water use in the manufacturing sector alone), even with the sub-sector's 51.31% decline in water use during this period; followed by *"Chemicals"* (20.52%) with a 45.86% decrease in water use. The third, *"Petrochemicals"* (15.15%), with a 54.02% water use reduction; fourth, *"Paper and printing"* (6.15%), showing a 51.64% decline; then, *"Food and Drinks"* being the fifth most intensive water user (5.32%) also indicated a 17.73% decrease in water use. For Scotland, from 2008/09 to 2014/15, *"Distilled potable alcoholic beverages"* took up the largest consumptive water (30.21%), but exhibited a 16.51% water use decline; the second, *"Basic pharmaceutical products"* (26.61%) had an 18.51% water use decrease; the third, *"Paper and paperboard"* (19.35%), revealing a 31.90% increase in water use; fourth, *"Beer"* (4.91%) with an 18.42% water use decline; then the fifth, *"Liquid milk and cream"* (4.26%) with a 0.42% reduction in water use between 2008/09 and 2014/15 also. Lastly, in Northern Ireland, from 2011-12 to 2013-14, *"Food"* used the largest water (57.39%) showing a 3.823% decline in water use during this period; *"Non Metals"* (10%) with 5.32% decrease; *"Electronics"* (8.77%) with 20.42% reduction; *"Chemical"* (8.76%) with a 10.12% water use increase; and lastly, *"Drink"* (6.33%) with an 11.68% decline in water use. To this end, with 80% of the products indicating a decline in water use, it is inferred that industrial water use in the UK is significantly declining.

Accordingly, of the 53 benchmarked companies, 3 companies' water use performance were ranked *"Excellent"*; 20 companies, *"Average"*; while the remaining 30 companies' performance were *"Poor"*.

In sum, it is envisaged that this project will lead to the definition of a methodology that can be applied to produce same outputs for sectors not covered in this initial project.

Dedication

This thesis is dedicated to my father, Mr. Dominic Ajiero and especially to my late mother, Mrs. Mary Ajiero (*requiescant in pace Mom*).

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Declaration Statement

ACADEMIC REGISTRY
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Name:	Ajiero Ikenna Reginald		
School/PGI:	Energy, Geoscience, Infrastructure and Society		
Version: *(i.e. First, Resubmission, Final)*	Final	Degree Sought (Award **and** Subject area)	Doctor of Philosophy (Construction)

Declaration

In accordance with the appropriate regulations I hereby submit my thesis and I declare that:

1) the thesis embodies the results of my own work and has been composed by myself
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*E-thesis Submitted (**mandatory for final theses**)*			
Signature:		Date:	

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Conference paper:

Ajiero, I. R. and Campbell, D. (2014) “Water – Energy Nexus, Problems and Prospects for the UK”, Smyth, B. and Jenkins, J. (Eds.), *Proceedings of the Water Efficiency Conference 2014, 9-11 September 2014, Brighton, UK: WATEF Network/University of Brighton*, pp. 106 - 120.

Journal paper:

Ajiero, I. R. (2015) "Integrating BIM with BMS in Energy Performance Assessment: Case Study of a University Building in UK", *International Journal of 3-D Information Modeling: Special Issue on Building Information Management (BIM) and Housing*, 4(1), pp. 19-44

Scoping studies for Mitsubishi Electric R&D Centre Europe (MERCE):

Ajiero, I. R. (2014) “Pumped hydro storage (PHS) schemes in Scotland - investigation into future developments”, Roaf, S. and Reay, D. (Eds.), *thermal and electric energy storage technologies for communities and buildings*, Final Report submitted to MERCE on the 21 July 2014

Ajiero, I. R. (2014) “Potentials of inter-seasonal solar energy storage systems in the UK”, Roaf, S. and Reay, D. (Eds.), *thermal and electric energy storage technologies for communities and buildings,* Final Report submitted to MERCE on the 21 July 2014

Ajiero, I. R. (2014) “Thermal energy storage in Scotland: systems and potentials”, Roaf, S. and Reay, D. (Eds.), *thermal and electric energy storage technologies for communities and buildings,* Final Report submitted to MERCE on the 21 July 2014

Award Received:

Ajiero Ikenna Reginald: Winner of the 2015 Michael Ventris Memorial Awards in Architecture, for the project titled: “Design and 3D modelling of an Enhanced Decentralized Wastewater Treatment Scheme for Flood Prone Semi-Urban Areas of Developing Countries”.

Chapter One

1.0 Introduction

This chapter provides a purview of the research; it neatly elucidates the impetus behind the study, thus serving as the research roadmap. In this segment, the research aim, objectives, statement of problems, hypotheses, scope/delimitation and outline of the research are succinctly presented. These shall serve as the theoretical synopsis of the research and means of gauging the study progress.

1.1 Background of the Study

Water, second only to fresh air as an indispensable requirement for the support of human life, covers ¾ of the earth's surface of which 97% is salt water, 2% is frozen, while 1% is fresh water which everyone on the planet has to share (Scottish Water 1999, p.1). Even more, in the view of the World Business Council for Sustainable Development (2009, p.3), sequel to the contemporary phenomenal climate and seasonal variations, the available global freshwater has now reduced to 0.5%, with a consequent increase (to 2.5%) in the frozen water locked up in Antarctica, the Arctic and glaciers, and not available to man (See figure. 1.1).

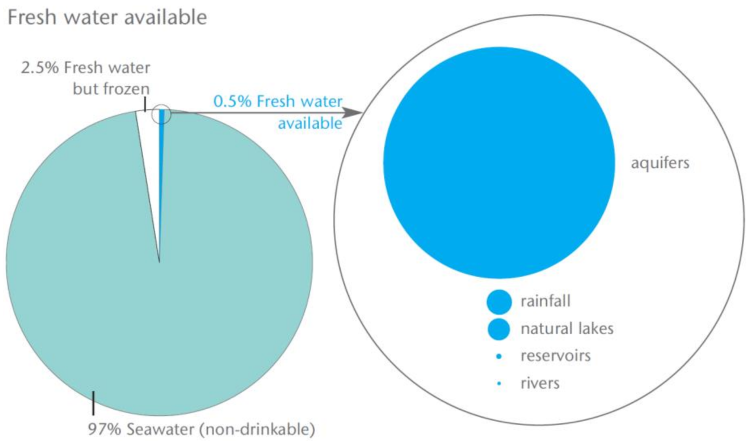

Figure 1.1: Global Fresh Water Availability

World Business Council for Sustainable Development (2009, p.3)

Globally, a breakdown of freshwater use shows that agriculture consumes the largest volume (about 70%), followed by the industrial sector (22%), while the domestic use stands at 10% (UNESCO 2003, p.19). However, fresh water usage is not the same at all places in the world given the population density, level of urbanisation and industrialization of different countries. This position is confirmed in the outcome of a joint research by the World Council for Sustainable Development and United Nations

Environment Programme (1998), which shows that the global freshwater use varies relative to the income status of different countries, ranging from 10% consumption in low and middle income countries to 59% for countries with high income (see figure 1.2).

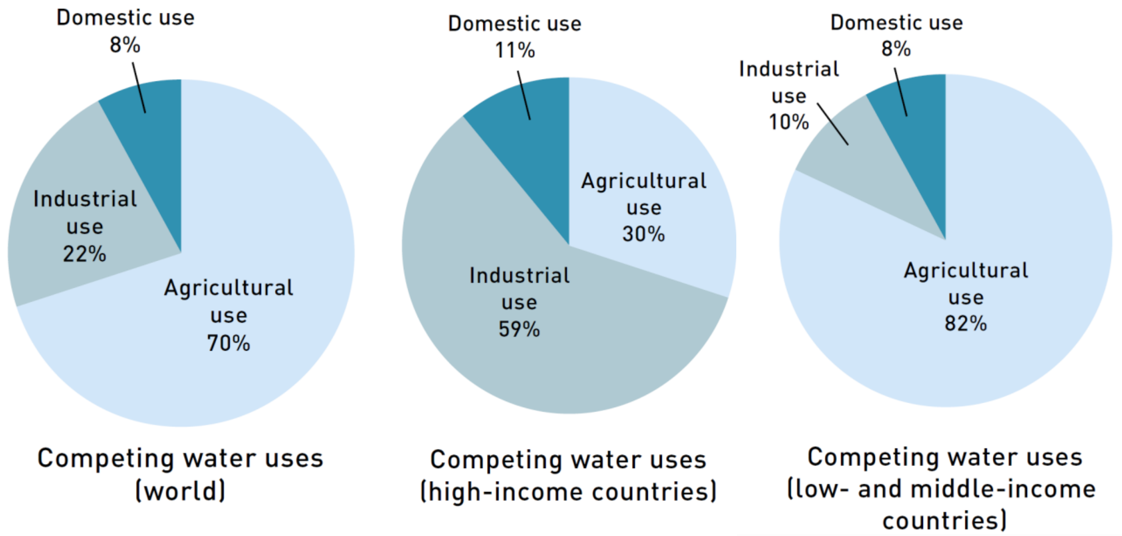

Figure 1.2: Competing water uses for key income groups of countries

UNESCO (2003, p.19)

The pie charts above explicitly show the effect of industrialization in high-income (developed countries) on the freshwater resource, and raise great concerns over how sustainable industrial practices in these countries are. Narrowing this global concern to the continents, a recent detailed research conducted by Hotloś (2008) on the continental use of freshwater, revealed that Europe uses a greater portion of its freshwater on industrial processes due to its advanced level of industrialization. Part of results of this research is revealed in the diagram below (figure 1.3).

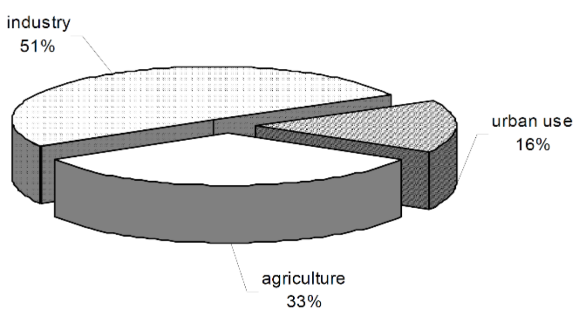

Figure 1.3: Fresh water use in Europe

Hotloś (2008, p.73)

In more specific terms, related studies by WBCSD and UNEP (1998) on how different countries use freshwater to meet various needs, show that there is a marked variation in the use of freshwater by each country. A summary of their findings is that India uses about 93% of its freshwater resource for agriculture, while United Kingdom records as high as 78% freshwater use for industrial purposes (see table 1.1). This report of an insignificant quantity of water use for agricultural processes (1%) is consistent with the result of a recent study by DEFRA (2013, p.104) that:

> *"Agricultural uses accounted for just 0.4% of recorded water abstraction in England and Wales in 2008. Regionally, this varied between less than 0.1% in the North West and Wales and 1.4% in the Anglian region and can be higher on a daily basis during the summer."*

Actually, there seems to be a downward trend in water use for agricultural purposes in UK, as according to the Author, the 0.4% water abstraction valued at 194 ML per day followed a 17% drop in 2007 and an earlier drop between 2004 and 2005.

These findings are thus indicative of the inference that although agriculture takes the largest share of fresh water withdrawal globally (70%), this condition does not apply to all countries.

COUNTRY	Agricultural	Industrial	Domestic and commercial
China	87%	7%	6%
Egypt	88%	5%	7%
India	93%	3%	4%
France	12%	71%	17%
Netherlands	32%	63%	5%
United Kingdom	**1%**	**78%**	**21%**

Table 1.1: Sectoral freshwater use by some selected countries

Saeijs & van Berkel (1995, cited in WBCSD and UNEP 1998, p.22)

A major concern therefore is to deduce the extent to which these water-intensive industrial activities in UK affect the available fresh water resource in terms of its current level of abstraction for industrial purposes and its probable future status, against the ever-increasing population growth in UK which according to the Office for the National Statistics (2009, p.1) stands at about 1000 persons per day.

UK industry greatly depends on water for its processes and productions. Both the extractive (or off-river) industrial water use: for manufacturing, as raw material, heat sink or coolant (thermal power), solvent and mining, to non-extractive (or in-river) uses such as hydro energy production and disposal of industrial effluents (Renzetti and Dupont, 2003), all rely mainly on the quality and classification of the water: *"pure,* *natural, salt, fresh, polluted, drinking, spring, mineral, bottled, tap, filtered, rain, raw, spa, distilled"* (Lalzad 2007, p.12).

Worthy of note is that unlike in the agricultural sector where irrigation as its major activity does not require treated water and is relatively a non-consumptive process, industrial processes are mainly consumptive and substantially need treated or portable water in order to meet the sectoral regulatory water standards. From the food, drink and beverage which require ample clean water to ensure uncompromised human health standards, to the rinsing of printed circuit boards which needs volumes of highly treated water (given that these products are extremely sensitive to microscopic contaminants), to the distilled water requirement of the chemical and pharmaceuticals, etc., industrial processes demand the use of water with high level of purity or treatment, and in no small measures.

Despite the stringent regulatory and statutory provisions on wastewater discharges, with the ever-advancing technological drive and industrialization of UK, the degree of industrial effluent pollution has recently become exacerbated. Food industries discharge wastewater mixed with high concentration of fat, oil and grease (FOG) which end up clogging the sewers and costing heavy sums to maintain the channels. Chemical plants discharge highly insoluble and non-biodegradable toxins as wastewater; the iron and steel sector discharges heavily metal-polluted wastewater, while nuclear plants discharge water containing traces of radioactive elements, biocides and nano-nuclides which form more complex compounds in the wastewater plants (European Environment Agency, 1999). Unfortunately, most of these contaminants do not get entirely removed at the treatment plants and in adverse cases, where treatment plants overflow, the wastewater and its teeming pollutants are discharged directly into receiving streams (DEFRA, 2012b).

It is also pertinent to state that water remains an indispensable resource for major energy generation in UK, including hydro, thermal and nuclear; in turn, great and growing measure of energy is required to operate and maintain water treatment and distribution facilities. This inextricable but intricate link between water and energy clearly presents both problems and prospects for assessment.

It is against this milieu that this research adopts *"benchmarking"* as a sustainability means of deducing how the UK industrial sector is performing in relation to its fresh water usage and its possible energy implications. This benchmarking process will involve collection of data on UK industrial water use, its processes and practices, selection of Key Performance Indicators (KPI) which will be used as yardsticks for measuring the *"Metric"* and *"Process"* performance of the UK industrial water use against member sectors.

Lastly, results of the comparison will be benchmarked against the *"Industry Best Practices"* or simply *"Bests"* in order to identify best practices which when adopted will boost the UK water users' market competitiveness and performance echelon, lower its water-related costs, increase its service level and enhance the industrial sector's sustainability credential in terms of fresh water usage.

1.2 Statement of Problems

In global terms, there is a greater focus on the domestic and agricultural water demand than on the industrial needs. As discovered by the WBCSD and UNEP (1998, p. X) the *"highest priority for scarce fresh water is given to domestic needs and then to farmers to grow food. Water for industry is often given relatively lower priority"*. Further, while there is an impressive body of researches and reports on agricultural and domestic water use, just a few have been published on industrial water use (Renzetti and Dupont, 2003 and Reynaud, 2002). This relative understudy of industrial water use has been mainly attributed to difficulty in collecting the requisite data for evaluating the sector's water usage (Reynaud, 2002), and in part, due to the vast composition and complexities of the industrial sector.

However, in recent times, there has been a growing interest in the fresh water use by the UK industrial sector, following the sector's peculiarly intensive fresh water consumption and highly polluted wastewater generation. Investigative reports in 1980 reveal that UK's industrial water use (abstraction) came to 79% which was the highest among other countries of Europe, America, Asia and Africa, while in 1991, UK's industrial water use reduced by 2% bringing it to 77%, yet it remained the highest industrial water consuming country in that year (World Resource Institute, 1988, 1998) (See table 1.2).

Country	Industry's % share in total withdrawals (year)	Industry's % share in total withdrawals (year)
Africa		
Algeria	5 (1980)	15 (1991)
Egypt	5 (1985)	8 (1993)
Ghana	3 (1970)	13 (1991)
Sudan	0 (1977)	1 (1991)
Zambia	0 (1970)	7 (1991)
Asia		
India	4 (1975)	4 (1987)
Japan	33 (1980)	33 (1987)
South Korea	13 (1976)	35 (1987)
Thailand	0 (1975)	13 (1991)
Americas		
Argentina	9 (1976)	18 (1991)
Canada	70 (1981)	73 (1991)
El Salvador	0 (1975)	4 (1987)
Mexico	5 (1975)	8 (1987)
United States	50 (1975)	45 (1991)
Venezuela	4 (1970)	11 (1987)
Europe		
Austria	77 (1980)	58 (1991)
France	71 (1984)	70 (1991)
Italy	16 (1981)	27 (1991)
Poland	62 (1980)	76 (1991)
Sweden	75 (1980)	55 (1991)
U.K.	**79 (1980)**	**77 (1991)**

Table 1.2: Industrial water use in continents and countries

World Resources Institute (1988, 1998, cited in Dupont & Renzetti 2001, p.413)

Furthermore, in 1995, UK's industrial water use stood at 78% and this again was the highest consumption among the assessed countries (Saeijs & van Berkel 1995, cited in WBCSD & UNEP 1998, p.22). More so, a more recent report by the Waste and Resources Action Programme (WRAP) (2011b, pp. 6-7) shows that both in water abstracted and the mains water supplied, the manufacturing sector alone (which based on the SIC 2007 is a subsector of the industrial sector) used up the highest volume of fresh water in UK.

Accordingly, appraising the food and drink sector, the UK's Department for Environment Food and Rural Affairs (2007, p.65) estimates that:

"The British food industry alone consumes approximately 900 megalitres of water each day, enough to supply almost three-quarters of all customers' needs in London daily".

On another note, the WBCSD (2009, p.4) points out that: *"the largest single use of water by industry is for cooling in thermal power generation"* and by extension, a major aftermath is that millions of fishes and other aquatic / wild lives are often trapped, chocked or killed in the cooling tower intake structure, while the warm water discharged into receiving streams end up increasing temperatures of the water bodies, disrupting its ambient conditions and impacting on the habitats negatively.

A key challenge facing any strategy to reduce freshwater demand in the UK is the belief that UK is a wet country with enough water to meet its present and future demands (Holt *et al.,* 2000 and Stern, 2013). However, a major problem is the country's spatial water distribution. Places like the Highlands of Wester Ross has as much as 3800mm average annual rainfall and 1040mm annual runoff, while parts of southern and Eastern England receive as little as 600-650mm average rainfall (Stern, 2013). England and Wales together have average annual runoff of 450mm (see table 1.3).

	Precipitation (mm)	Runoff (mm)	Resources per capita (m^3 x 10^3 / year)
Switzerland	1500	1000	5.9
Norway	1450	1250	92.8
Scotland	1440	1040	15.6
Austria	1200	670	7
Iceland	1200	1750	650
N. Ireland	1060	640	5.3
Italy	1000	600	3.2
Portugal	900	220	2
England and Wales	890	450	1.3
Belgium	850	360	1.1
France	750	300	2.8
Netherlands	750	250	0.7
Czech Rep.	720	220	1.7
Germany	700	260	1.1
Romania	700	190	2
Cyprus	500	50	0.6

Table 1.3: Water resources in selected European countries

Marsh et al. (1994, p.7)

It is worth highlighting that in the UK as a whole, there is approximately 2650m^3/year of water per person (Kaczmarek, 1995). This places UK in the category of "*low*" water availability (Table 1.4) (Holt *et al.*, 2000), and makes the country *"less water available per head than any other EU country"* (The Institute of Grocery Distribution, 2007).

WATER AVAILABILITY	VOLUME OF WATER (m^3 per annum per person)
Catastrophically low	<1,000
Very low	1,000 – 2,000
Low	2,000 – 5,000
Medium	5,000 – 10,000
High	10,000 – 20,000
Very High	>20,000

Table 1.4: Global water categories and availability percentages

Townsend et al. (2009, p.411)

Unfortunately, areas like England and Wales that have *"very low"* water availability of about 1400m^3/year, have the highest population density, industrial activities and projected increase in water demand (Holt *et al.*, 2000).

Consequently, beyond the water consumption by the industrial sector of UK is the wastewater generation which has become a rising concern to the water companies and the UK regulators. As noted by the Arthur and Blanc (2013):

> *"There are approximately 200,000 sewer blockages throughout the UK every year of which up to 75% are caused by fat, oil and grease … these have led to sewer flooding and odour problems; clearing these blockages cost millions of pounds a year which is reflected in the customers' bills."*

A major concern in the industrial wastewater generation is that with the ever emerging dietary changes, industrial wastes keep increasing and becoming more varied and toxic, and extra difficult to degrade or dispose of (Robins and Kumar 1999, p.76). Reports from UNESCO reveal that about *"300-500 million tons of heavy metals, solvents, toxic sludge and other wastes accumulate each year from industry"* (UNEP 2012, p.9), while according to European Environment Agency (1999) and Water UK (2007), a greater threat to the fresh water quality is seen in the emerging industrial pollutants such as the pharmaceuticals, personal care products, nano-materials, biocides and radio-nuclides; some of which are non-biodegradable while others are endocrine-disrupting chemicals which create great risks in fish consumption.

With recent estimates suggesting that there are thousands of toxic chemicals from industrial processes capable of causing cancer, including: Arsenic, lead, ammonia, etc., a greater worry lies in cases where such industrial wastewater escapes into the streams untreated even after getting to the treatment plants. According to DEFRA (2012b, p.5):

> *"Currently, around 16 million tonnes of untreated wastewater is discharged in a typical year from overflows at Abbey Mills pumping station to the river Lee in Stratford area of London".*

There is therefore an indispensable need to evaluate and benchmark the industrial sector's use of freshwater in UK, in order to identify the processes that use water intensively and generate toxic wastewater; this will help in recommending suitable improvements strategies that will aid a remarkable reduction in the sector's high water use and wastewater generation.

1.3 Aim and Objectives

This study is principally aimed at benchmarking the industrial use of water in the United Kingdom, and identification of best practices associated with the country's industrial processes and practices. To accomplish this goal, the project shall concentrate on the following specific objectives:

1) To critically review cognate literature on benchmarking of industrial use of water globally, and specifically in the United Kingdom.
2) To identify prevailing gaps in UK industry's water use data.
3) To source and collate requisite data on industrial use of water in UK, broken down in accordance with the UK Standard Industrial Classification (SIC) of economic activities.
4) To deduce and adopt Key Performance Indicators (KPIs) and metrics for conducting the benchmarking of water use in the UK industrial sector.
5) To develop and standardize a benchmarking tool which integrates the adopted KPIs and metrics using a suitable software development platform.
6) To empirically analyse how much water is used by each industrial subsector and identify corresponding water-intensive activities.
7) To make suitable recommendations on best practice industrial water saving measures based on the study findings

1.4 Research Hypothesis

To address the above-mentioned research objectives and investigate specific areas of this study, the following major hypotheses (Null: H_0) are proposed:

1. There is no statistical relationship between UK's population growth and its use of water for industrial (manufacturing) purposes.
2. There is no significant variation in annual water use among the industrial, agricultural and domestic sectors of the UK, from year to year.
3. Rates of annual water use (relative to production) by UK production (manufacturing) companies do not significantly vary.
4. *"Absolute"* freshwater water use by the industrial subsectors or divisions (classified according to the SIC) from year to year, do not statistically differ.
5. There is a growing trend in water use by major water intensive product of the UK industrial sector, over time.
6. Energy consumption rates of major UK industrial processes have remained equal over years.

1.5 Research Questions

I. Why should industrial water use in the UK be benchmarked?

II. What are the most water-intensive processes in the industrial sector?

III. UK is a highly industrialised country; thus, its industrial water use will remain high and even increase with the imminent population increase over the coming years. How true is this statement?

IV. What are the most appropriate water use metrics for benchmarking water use by industry in order to reveal the true performance status of the benchmarked Sites?

V. What are the possible water conservation strategies to optimally reduce water use by the UK industrial sub-sectors?

VI. Is there any measurable relationship between UK water and energy use?

1.6 Research Methodology and Methods

A major challenging requirement of every research process is the selection of an appropriate research methodology, approach and method. In good researches, the underlying requirement in the view of Denscombe (2003) is that *"the choices should be appropriate, reasonable and explicit; neglecting these fundamentals which will lead to very poor research, may open the research findings to criticisms and doubts"*.

Selection of the suitable research tool for any study is fundamentally informed by an in-depth understanding of the subject matter through review of previous studies undertaken in same or related field(s). Accordingly, the nature of the data to be gathered also helps in framing the decision of an appropriate methodology for any academic research.

This research intends to bridge the gap of limited researches in the area of UK industrial water use, create a clear understanding of the process and metric use of water by the industry and deduce water use best practices, specific to the industrial sector.

To this end, as a case study research, the paradigm for this research shall be positivism (quantitative). These quantitative analyses will empirically reveal how water is used by the UK industrial sector, relative to other sectors. The research methods shall include a detailed study and appraisal of literature on water use in the UK; collection of data from UK water companies, trade bodies, environment regulators and private firms; development and use of a benchmarking tool to establish the performance status of the UK industrial sector, subsectors and processes.

1.7 Significance of Study

Ultimately, the aim of every benchmarking process is to improve performance through comparison of a sector's performance against those of high-performing related organisations and adapting of established best practices. The need to benchmark the industrial sector's freshwater use became heightened following the unusual increase in industrial water use in the UK by 37% between 1991 and 1995 (Baker and Tremolet, 1999). This has also been intensified by the contemporary and emerging status of the water resource in UK and the corresponding legislative imperatives. Several researches have revealed that more than ever before, industrial processes, practices and systems have been subjected to increasing stringent environmental regulations, particularly regarding its freshwater abstraction and wastewater discharge (Atimtay and Subhas, 2011; Suvio, 2012 and Holt *et al.*, 2000).

Further, it is noteworthy that the status of the fresh water resource generally, is already of great concern to Governments at different levels. In Europe, the emergence of the Water Framework Directive in 2000 *"resulted in a new holistic approach to water management, including the licensing of water abstraction, the control of diffuse pollution and the consideration of flow regimes in environmental standards"* (SEPA, 2010). The EU Directive which constitutes one of the legislative water requirements, projects that by 2015, *"member states must be working towards ensuring that all water* *bodies reach 'good' ecological status, and that they then actually achieve this status by 2027"* (Royal Geographical Society 2012, p.10).

In England and Wales, the Environment Agency is saddled with the responsibility of improving and preserving the quality of *"controlled waters"*; it applies its responsibilities to industry through environmental regulations (Suvio 2012, p.5). The Scottish Environment Protection Agency just as the Northern Ireland Environment Agency monitors water levels and river flows, and actively ensures the sustenance of the water resources within its region.

Although these regulations should frame the practices in water use, but for a holistic solution to the exacerbating water issues in UK to be achieved, the driver should be sustainability, this involves encouraging all water users to go *"beyond compliance"* and stimulate sustainable practices throughout the water use process cycle (Kumar and Robins, 1999).

In times past, negative effects of climate variability have greatly taken their toll on UK, leading to drought and flood flashes. In 1984 Western Britain recorded a surface water drought, from 1988 to 1992, Eastern England experienced groundwater drought, then lasting for two years was the drought which began in 1995 (Holt *et al.*, 2000). These environmental conditions have still not improved in recent times, as places like South East England in 2011-12 experienced yet another drought due to the low autumn and winter rainfall continuing into a dry spring (RGS 2012, p.22). The Royal Geographical Society (2012) has further predicted that with the increasing population concentrating in the already water stressed areas and places with recurring drought, UK will face a greater challenge in sustainably providing water services to meet the demands of various sectors in the next 20 years if identified causative practices and processes are not corrected on time.

Consequently, water quality impacts on air quality, these are inextricably linked; water purification and supply is energy intensive, with about seven grams of CO_2 generated for every litre of water treated to drinking water standard (RGS 2012, p.18). Accordingly, as posited by DETR (1998, p.1):

> *"Pumping costs UK industry over £1,400 million in electricity each year, mostly for pumping water, and estimates suggest that over 20% of this figure could be saved. On a typical industrial site, pumping is the single largest user of electricity and accounts for over 20% of the total electricity bill".*

Water remains fundamental to industrial growth in UK and the need to conserve its use remains indispensable. A growing concern is seen in the need for portable water in high volumes for most industrial processes. Actual water (not embedded) required for industrial processes and products is often amazing when measured. According to Atimtay and Subhas (2011, p. IV):

> *"0.375m^3 water is used to produce paper of \$1 (61p) value, 2650 U.S. gallons (12.04714m^3) to produce one pound (0.454kg) of coffee, and 400 gal (1.82m^3) to produce one pound (0.454kg) of sugar".*

Suffice it that the industrial sector contributes immensely to the UK's total economic growth in terms of its gross added value. As asserted by the Food Industry Sustainability Strategy (2007, p.16):

> *"The food manufacturing sector has a turnover of approximately £70billion, £800million of which is used on energy and £300 million (less than ½ a percent of turnover) is water expenditure. As water is a key part of the manufacturing process, in times of shortage where supplies are threatened its value may become much higher than its nominal cost. Nonetheless, a 20% reduction in water use could save the food manufacturing industry £60 million a year".*

There is therefore the prevailing need to identify possible means of saving water in industrial processes, and benchmarking is considered as an effective way of achieving this target. Application of benchmarking to improve on performance in water use is usually obtained at a comparatively low cost, yet its water, energy and financial benefits or merits are always significant. The metric benchmarking will lead to volumetric reduction in industrial water consumption while process benchmarking will help identify the best water business practices.

Thus, it is within the target of this research to discover or uncover the water intensive processes, through the development of a benchmarking tool for comparison of water use across the industrial subsectors and identification of ways of minimizing the sector's freshwater use.

Although the industrial sector is at the heart of this research, the academia, water undertakings, Government, consumers or direct users, water and effluent regulators, indirect stakeholders, pro-active stakeholders, policy-making bodies and financing agencies will find this report resourceful for policy making decisions and improvement on their current performance (Alegre, *et al.*, 2006); This goal ties in well with the opinion of Water Colorado (2007) that water benchmarking informs conservation policy / decision making related to water budgeting / allocation.

The benchmarking process which involves performance assessment and performance improvement (EBC, 2012) will boost the UK industrial sector's water and service quality, reliability, sustainability and financial efficiency.

This study will therefore have a national and international impact; it will provide a sustainability tool that water operators can access to benchmark their current performance in industrial water use, identify gaps in their practices and corresponding prevailing opportunities for improvements in efficiency and effectiveness, as well as enhance the overall business competiveness of the UK water sector.

1.8 Scope / Delimitation

This research is limited to the use of water in the United Kingdom, especially by the industrial sector which is the specific case study. Thus, to ensure that the topic is researchable in terms of the inherent research duration limit, data requirements and cost, and for a comprehensive research on the subject matter, data to be collected shall be limited to a maximum of a fifteen-year period (2000 – 2015). These will principally frame the scope of the empirical analysis.

With the aim of benchmarking the industrial use of water in UK and identifying best practices associated with the industrial processes, this study shall focus on analysing in details, data collected from the water utility companies, trade bodies and environmental regulators, and from other considered relevant sources such as Envirowise, UK Water, WRAP, BIER, DEFRA, etc.

1.9 Dissertation Outline

This thesis comprises of delineated research activities presented in seven chapters, heralded by the Abstract, Contents, Figures and Tables as the preliminary pages and completed with References and Appendices to disclose the used or accessed information sources and reveal detailed requisite analyses or illustrations.

Considered as the research pointer, chapter one shall provide the framework of the major research activities to be undertaken. This chapter launches the reader into the study milieu by explaining the fundamentals of the subject matter and presenting the research *rationale* or justification in the form of problem statement. These shall help structure the aim and objectives of the study. Accordingly, a set of purpose-imbued hypotheses to be later tested for validation purposes are proposed in this chapter, while carefully structured questions are offered to address important aspects of the research. The stated scope/delimitation gives the research extents; it underscores the need for a detailed work in a particular area of interest and presents how the researcher will go about achieving the proposed aim within the given time frame of the study.

Chapter two provides a critical review of research and development in the freshwater use by the UK industrial sector. It reveals an in-depth overview of various literatures that explain how the water resource in UK enhances the processes and practices of the industrial sector. It reviews previous researches and reports in this area in order to give the requisite context for the study of water use in UK. This segment finally explains strategic approaches to adapting the considered prevailing and applicable practices so as to achieve an optimal performance in the fresh water use by the UK industrial sector.

In chapter three, a critical appraisal of benchmarking strategies applicable to the water industry in different parts of the world is clearly detailed. The chapter explains the pros and cons of various benchmarking processes, thus shapes the decision for selection of a benchmarking type pursuant to the motive behind the benchmarking effort. With the goal of understanding the practical application of benchmarking in the water industry, it establishes what types of benchmarking tools are currently in use, studies their application mechanisms and explores ways of designing a more comprehensive, user-friendly and easy to understand benchmarking software for industrial processes. Put precisely, chapters 2 and 3 encapsulate papers reviewed in both water use and benchmarking. These chapters carefully articulate the reviewed research efforts in a way that ensures that the information flow is consistent and the substance of this research work is clearly communicated.

Chapter four presents the development of appropriate methodology and corresponding methods for this study. It provides details of how and where data to be used for the analyses shall be sourced. In this segment, suitable statistical tools for the data analyses are provided and the basis for verification of the research results is given.

Chapter five encapsulates the software development requirements, selection of an appropriate computer language for the tool, and explanations of functionalities of the tool. In this chapter, using the developed *i*-Water tool, process performance benchmarking is conducted with the data collected. Subsequently, results of this benchmarking exercise are presented for inference to be drawn on how the benchmarked companies or sectors are performing.

Chapter six contains the data analyses and interpretations of the results. Where considered necessary, this chapter shall condense the results of these analyses into tabular or graphical representations. However, very comprehensive data analyses are taken to appendices in order to keep this chapter as concise as possible.

Sequel to the results provided in chapter six, chapter seven features a comprehensive summary / discussions of the metric and process benchmarking results, as well as results of the data analyses carried out using the Minitab software which is adopted for the statistical analysis. In this section, the performance status of the UK industrial sector (in terms of water use) as a whole and by each subsector is succinctly captured. This chapter thus gives a conclusion of the research findings. The inference made at this juncture will be based on the literature review, and the metric and process benchmarking results and the statistical analysis outcome. To this end, considering the prevailing research limitations (where this is the case), the need or otherwise to open this work to further researches shall be made.

Chapter Two

2.0 Introduction

This chapter presents a detailed appraisal of literature on water use generally, and particularly in the UK. It captures best – in – class practices associated with industrial water use globally and how best to apply same to UK water utility in order to achieve an optimal performance in water use by the industrial sector.

In this chapter, a critical review of research and development in freshwater use in the UK is provided with a view to deducing the water stress patterns and areas of water pressure in the UK. Comprehensive information and data from Office for the National Statistic (ONS), Department for Environment, Food and Rural Affairs (DEFRA), Environment Agency (EA), Scottish Environment Protection Agency (SEPA), Waste and Resources Action Programme (WRAP) and water agencies will be accessed to establish discrete trends of industrial water use in quantitative and qualitative terms.

Further, disaggregating the UK water use into regions, this review elucidates the parts of UK that use greater portions of the fresh water resource for industrial purposes. Whereas industrial water use is process-specific, various industrial subsector processes will be appraised with the aim of identifying the water-intensive activities and potentials for significant water savings.

It is therefore envisioned that a good understanding of the previous industrial water use trends and what efforts have been made to ensure optimal use of the freshwater resource will set the context for the empirical assessment of water use by the industrial sector of the UK.

2.1 Global Use of the Fresh Water Resource

2.1.1 Water use: Withdrawal and Consumption

A critical assessment of recent literature on the available fresh water reveals a striking, steady decline in the water resource, both globally and more intensely, in specific parts of the world. It is troubling to note that in contemporary times, inland waters and major lakes are rapidly diminishing due to heavy abstractions for industrial and agricultural purposes. A related research conducted by Grobicki (2008) discovered that water volume in the Aral Sea has reduced by 75% in comparison with its volume in 1963. Accordingly, Lake Mead, the largest reservoir in America has now reduced by 30,480 mm lower than its historic levels (Webber, 2008). Furthermore, one of the world's largest rivers in the world, Yellow River in China, which used to be over 4000 km long can no longer reach the sea since 2002 following the over-extraction of its water by industry and agriculture, and being the source of water to over 120 million people living around the river basin (Grobicki, 2008).

As evaluated by UNEP (2002, p.157), out of the 1400,000,000 km^3 of total water on earth, 35,000,000 km^3 (2.5%) is freshwater, while only 10,500,000 km^3 (i.e. 0.3% of the 2.5%) is available for the economic needs of man and the ecosystem. Accordingly, the last century population growth from 1.6 billion to 6 billion and consequent agro-irrigation climaxing to 267 million hectares from 50 million hectares, in turn, increased freshwater withdrawal by a six-fold from 580 billion m^3/year to 3700 billion m^3/year by year 2000 (Gleick, 1993). Figure 2.1 diagrammatically explains how this invaluable fresh water resource is used up by various continents.

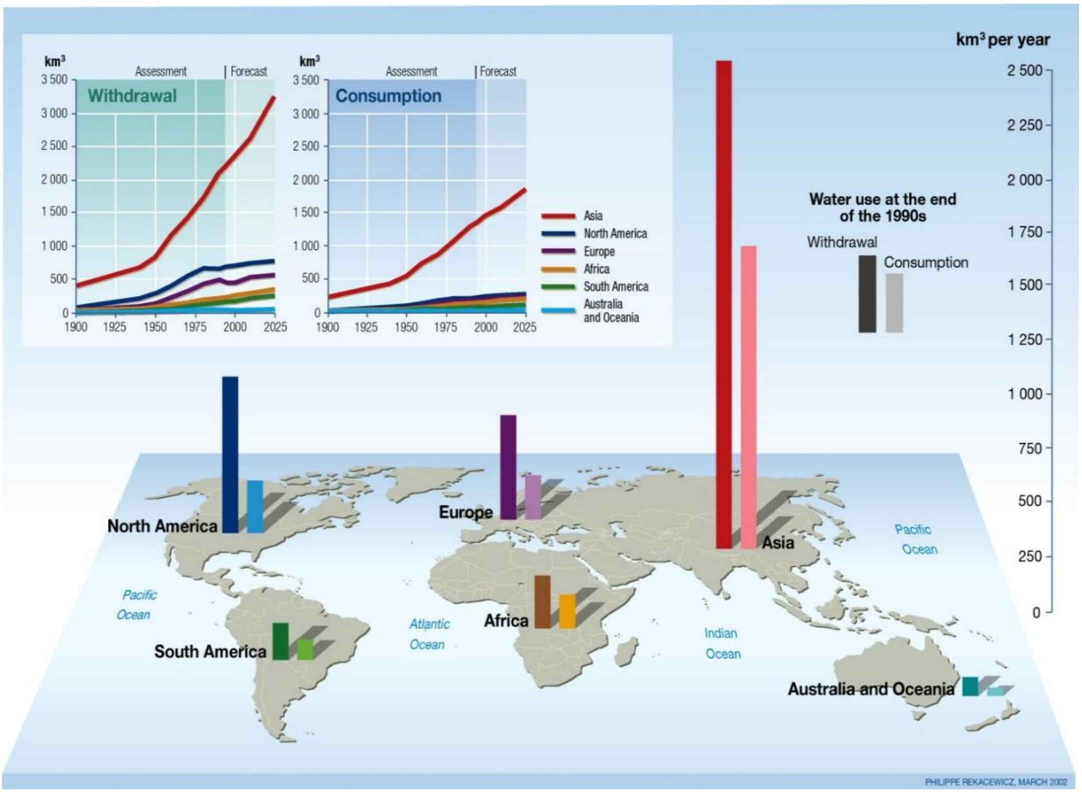

Figure 2.1: Continental Water Withdrawal and Consumption: The Big Gap

Shiklomanov and UNESCO (1999a) and World Resource Institute (2000)

From figure 2.1, it is evident that Asia's water use constitutes approximately 57% withdrawal and 70% consumption of the global water. This has been attributed to the largest irrigated lands of the world being located in Asia (UNESCO, 2002). Further, global water withdrawal rate with reference to the year 1995 stands at 3790 km^3/year while consumption totals 2070 km^3/year (61% of withdrawal), with estimates that this will keep increasing by 10 – 12% every ten years, attaining 5,240 km^3 by 2025 (1.38 times the 1995 figure) (UNESCO, 2002).

A holistic approach to reducing water use globally requires a comprehensive assessment of water related activities in continents and countries in order to clearly understand prevalent activities that are water intensive and location specific. This is considered germane given that due to climate / weather variations, cultural differences, and varying practices, not all countries are heavily involved in agricultural activities requiring irrigation which currently constitute the biggest source of water withdrawals globally. This can be applied to highly industrialised and less agro-based continents such as Europe where 51% of the fresh water resource is used for industrial purposes, 33% for agriculture and 16% for urban use (Hotloś, 2008, p.73).

2.1.2 Fresh Water Stress and Scarcity

The earth is considered as a water planet, yet maps and indices of water scarce and stressed areas continue to grow with very severe and increasing water shortage and drought in many areas of the world following pressures from population increase, seasonal and climate variations and heavy industrialization. In the extreme, the contemporary concern of *"water crisis"* is predicted to escalate into "*wars over water*", given the rapidly growing insecurity in freshwater supply globally (Ellis, *et al.*, 2001). This condition does not actually connote absence of water; rather it stresses the increasing limitedness of the accessible freshwater resource relative to the inaccessible frozen forms and abundant sea volumes with its attendant high cost / energy intensiveness of desalination.

Critical studies of past literature show that the available and accessible fresh water resource has continued declining from 1% or 0.78% in 1999 to 0.5% as at 2009. These findings are summarised in Table 2.1.

Research Efforts by:	**Salt Water**	**Fresh Water**	
		Frozen (Glaciers and permanent snow cover)	**Accessible to man and the Ecosystem**
Scottish Water (1999)	**97%**	2%	**1%**
UNESCO, State Hydrological Institute and Shiklomanov (1999)	**97.50%**	2.50%	
		68.9% of 2.5 = 1.72%	31.1% of 2.5 = **0.78%**
Intergovernmental Panel on Climate Change (IPCC) (2007)	**97.50%**	2.50%	
		70% of 2.5 = 1.75%	30% of 2.5 = **0.70%**
WBCSD (2009)	**97.50%**	2.50%	**0.50%**

Table 2.1: Global water availability and accessibility

Water in the actual sense is not diminishing; rather, this essential resource is naturally unequally distributed and mainly not always available where it is needed. Unfortunately, this is the case in the UK where Scotland alone, constituting only 8.4% of the UK population (going by the 2013 population), has about *"90% of the volume and 70% of the total surface area of the entire freshwater in the UK"* (UK National Ecosystem Assessment 2011, p.2 and Scottish Heritage 2001, p.7). This condition is mainly attributed to Scotland's *"extensive Western seaboard"* being providentially *"… exposed to the full force of the North Atlantic Ocean and Eastern coastline bordering the North Sea …"* with *"… the most energetic and extreme marine environments in the Northern hemisphere"* (Water Scotland 2009, p.9).

Known as the hydrological cycle, water taken up to the cloud through evapotranspiration and vaporisation, returns mainly as rainfall to restore the water resource and maintain the soil moisture content; but this condition depends greatly on location. In some parts of the world, rain falls scantily; some others, moderately and in others, heavily. Sometimes this is exacerbated by effects of strong winds which end up as flood in some areas.

Water stress is growing globally due to high population density, urbanisation, industrialization, and extreme weather conditions; these conditions have led to degrees of aftermaths such as drought, destruction of aqua habitats and death of water creatures. Unfortunately, water stress is projected to keep increasing especially as the population of urban migrants remain on the increase in the already water stressed countries (RGS, 2012). Figure 2.2 reveals the water stress pattern in various parts of the world.

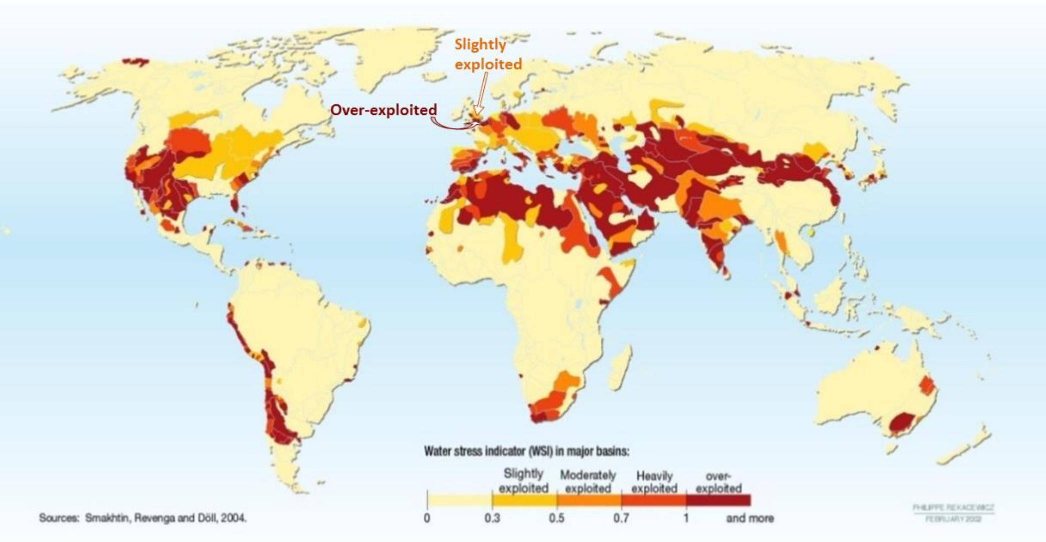

Figure 2.2: Water Stress Indicator (WSI) in Major Basins

Smakhtin and Doll (2004)

It can be deduced from figure 2.2 that the freshwater resource in areas of UK such as the East and South Anglia (England), is already over-exploited while other parts are slightly-exploited; this supports the position of DEFRA (2008, cited in RGS 2012, p.3) that in some parts of the UK, abstraction is already beyond its *"environmentally sustainable level"*. A striking aftermath of the freshwater use status of UK is revealed in the findings of the Environmental Agency (2009) cited in RGS (2012) that:

> *"On a world ranking of water availability – from most to least – southeast England would be 161st out of 180 world regions. Increasing population and housing growth will increase water demand by 5% or an extra 800 million litres of water per day by 2020"*.

Notwithstanding that on the average, UK has a water availability of about 2650m^3/person/year (Kaczmarek, 1995), but this is not evenly distributed across the country. Figure 2.3 gives a clear pictorial representation of water availability distribution in geographical terms. It shows that places like the south-east Anglia have water availability of less than 1000m^3/capita/year, while Northern Scotland alone has as much as 4000m^3/capita/year and even more. In particular, London's water availability classification of 250m^3/year places this region in the *"very low"* category, and this condition is unlikely to improve, as the increasing demand for housing follows demographic trends (Griggs, 1998). This condition of UK's uneven distribution of water availability follows the point that in the UK, *"parts of the western Highlands have average annual rainfall totals in excess of 4000mm - rising to 7000mm in exceptionally wet years"* (Natural Environment Research, 1991); whereas, *"significant areas in the eastern lowlands average less than 700mm, declining to approximately 600mm in a few coastal localities"* (Marsh and Anderson, 2002).

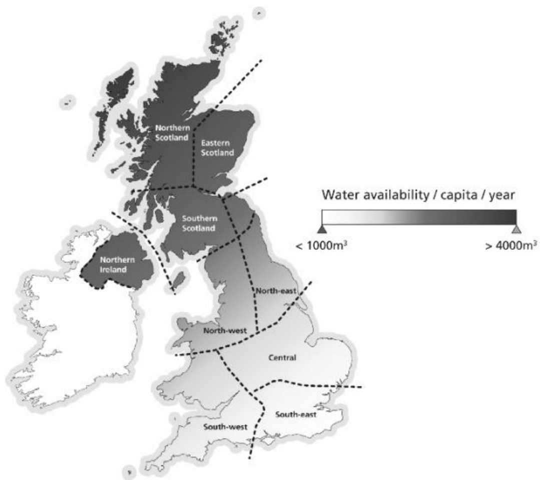

Figure 2.3: Map of UK water availability per capita

Staddon (2010, cited in RGS, 2012, p.2)

The Scottish and Northern Ireland Regions of UK have providential abundance of the freshwater resource, therefore are not water stressed. A strategic approach to assessing how water stressed an area is, involves mapping the population density of such place against its rainfall distribution. The approach according to RGS (2012) explains where the future water availability of the UK lies: England which constitutes 84% of UK population has an annual rainfall as low as 600 – 650mm/year while Scotland with over 90% of the water volume in UK holds only 8.3% of the UK population and has rainfall as high as 3800mm/year (UK National Ecosystem Assessment 2011 and ONS, 2013).

2.2 Research and Development in Water Use by Industry

2.2.1 Trends in water use by the industrial sector globally

Categorised as *"facilities that mainly manufacture or process materials as defined by the Standard Industrial Classification (SIC) code numbers 2000 through 3999"* (US WaterSense 2009, p.3) the industrial sector's need for water can be considered as *"dynamic"*; this is because it is both process and country-specific. For instance, not all industrial processes require water of drinking standard or water of high specification such as sterile water used for the manufacture of chemicals, pharmaceuticals or chipboards. Also, industrial water use according to UNESCO (2003) remains a function of countries' national income with as low as 10% in low and middle income countries to as high as 59% in high income countries. Therefore, though on a global note agriculture takes the highest percentage of water (70%), in terms of the national income of countries, there is a growing competition in water use between the industrial and agricultural sectors. As revealed in figure 1.2, in high income countries, the industrial use of water which stands at 59% supersedes the agricultural use which is 30%; while in contrast, the agricultural use of water in the low and middle income countries (82%) is well in excess of the 10% for industrial water use.

A critical overview of global industrial water use from past to present shows that industrial water use is on a steady increase. As empirically captured by Grobicki (2008, p.4),

> *"In the 50 years from 1950 to 2000, world industrial water withdrawals climbed from 200 km^3/year to almost 800 km^3/year, while industrial water consumption has increased from 20 to about 100 km^3 /year."*

However, there is need to understand how various continents of the world use the fresh water resource industrially in order to identify increasing or decreasing water use patterns in these continents and possible reasons for this trend. Figures 2.4 – 2.10 reveal actual and estimated volumes of water used by industry in all continents, and globally.

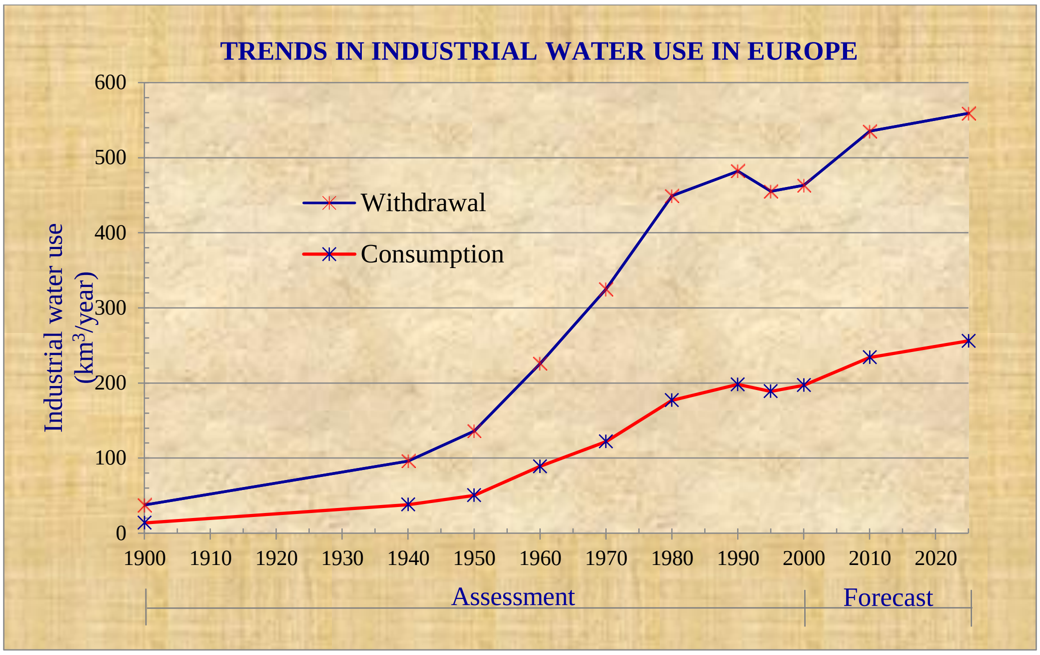

Figure 2.4: Trends in industrial water use in Europe

Data Source: Shiklomanov (2002)

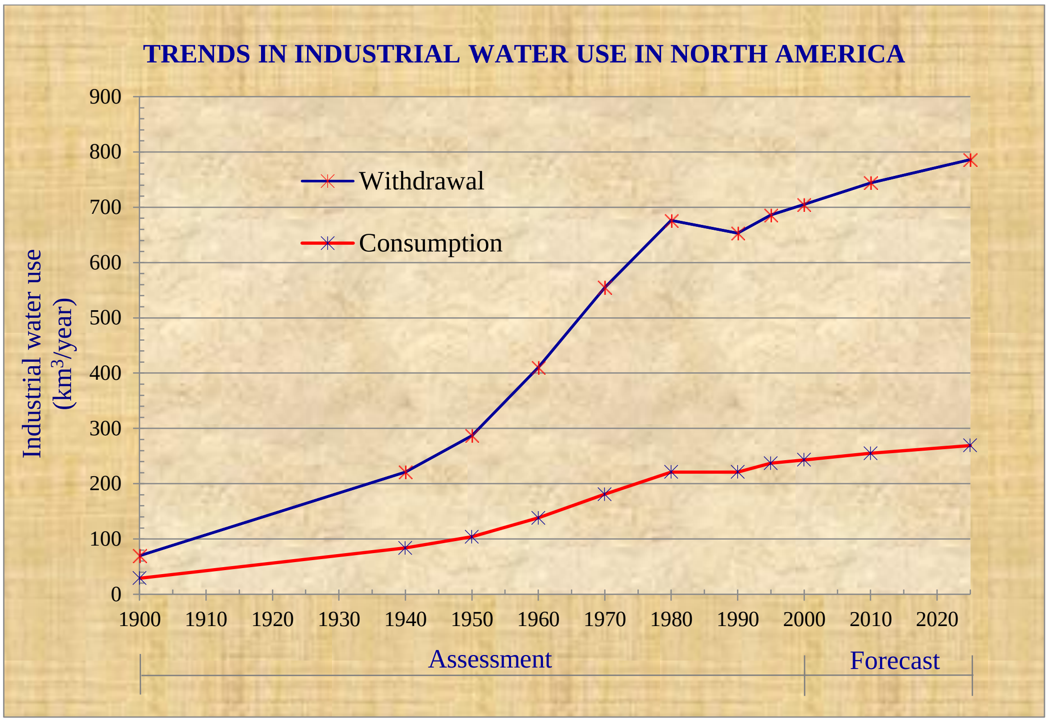

Figure 2.5: Industrial water use trends in North America

Data Source: Shiklomanov (2002)

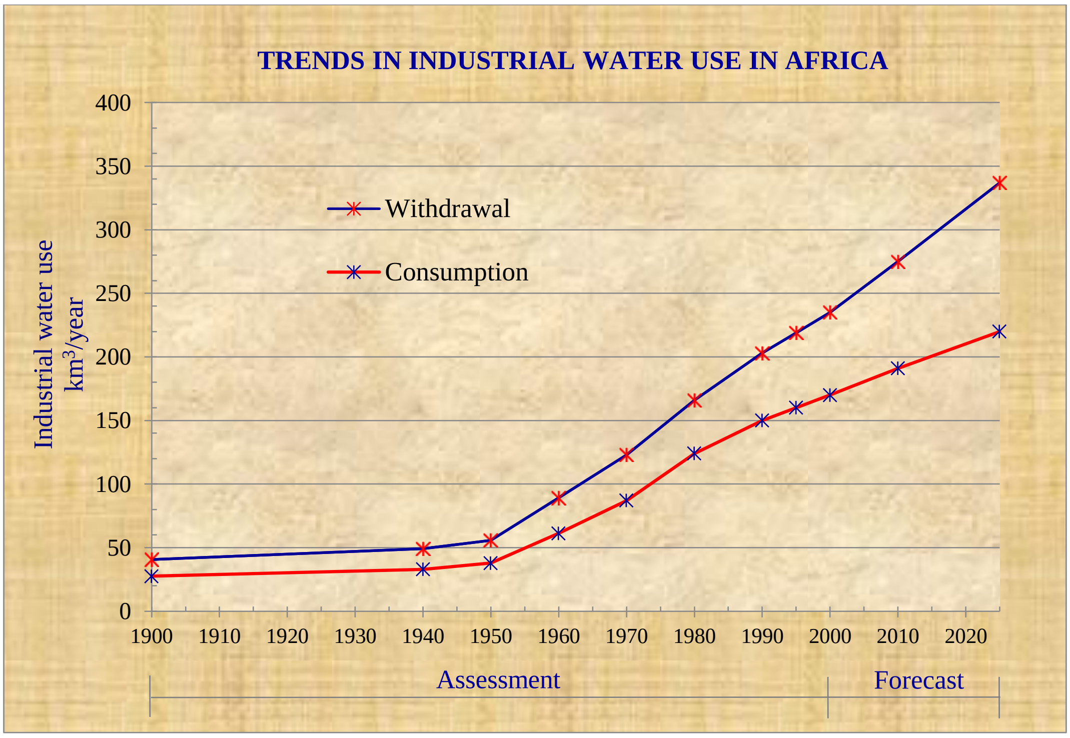

Figure 2.6: Trends of industrial water use in Africa

Data Source: Shiklomanov (2002)

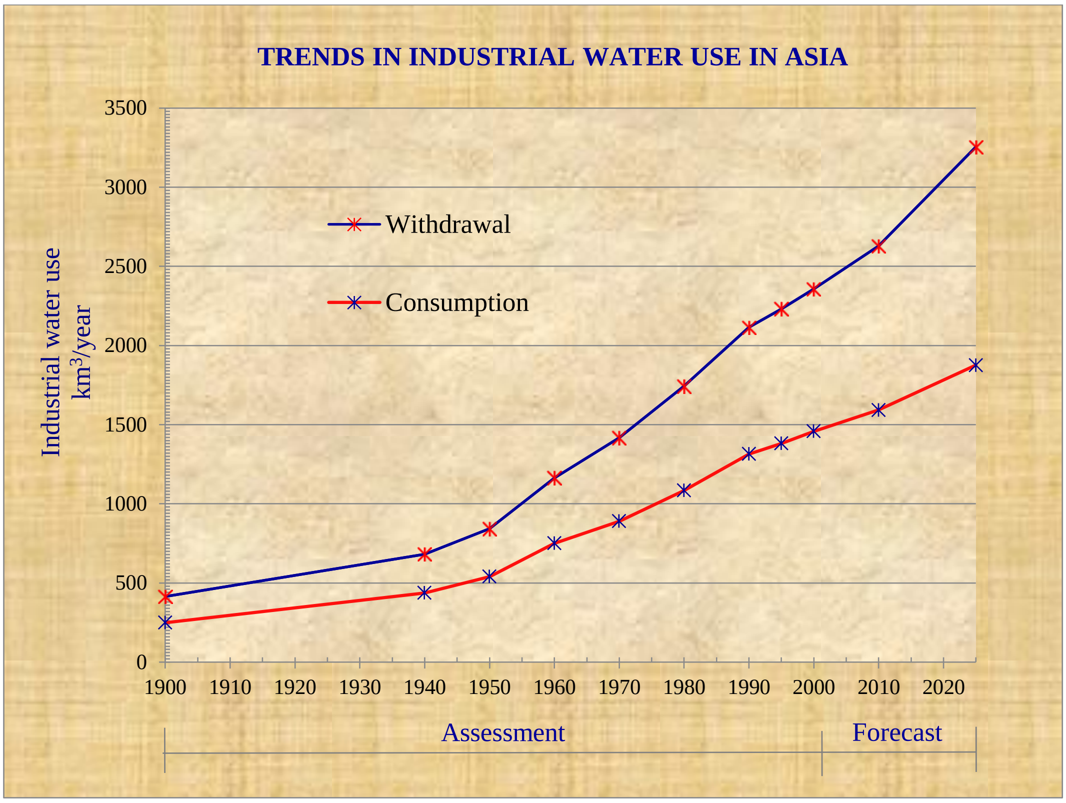

Figure 2.7: Trends of industrial water use in Asia

Data Source: Shiklomanov (2002)

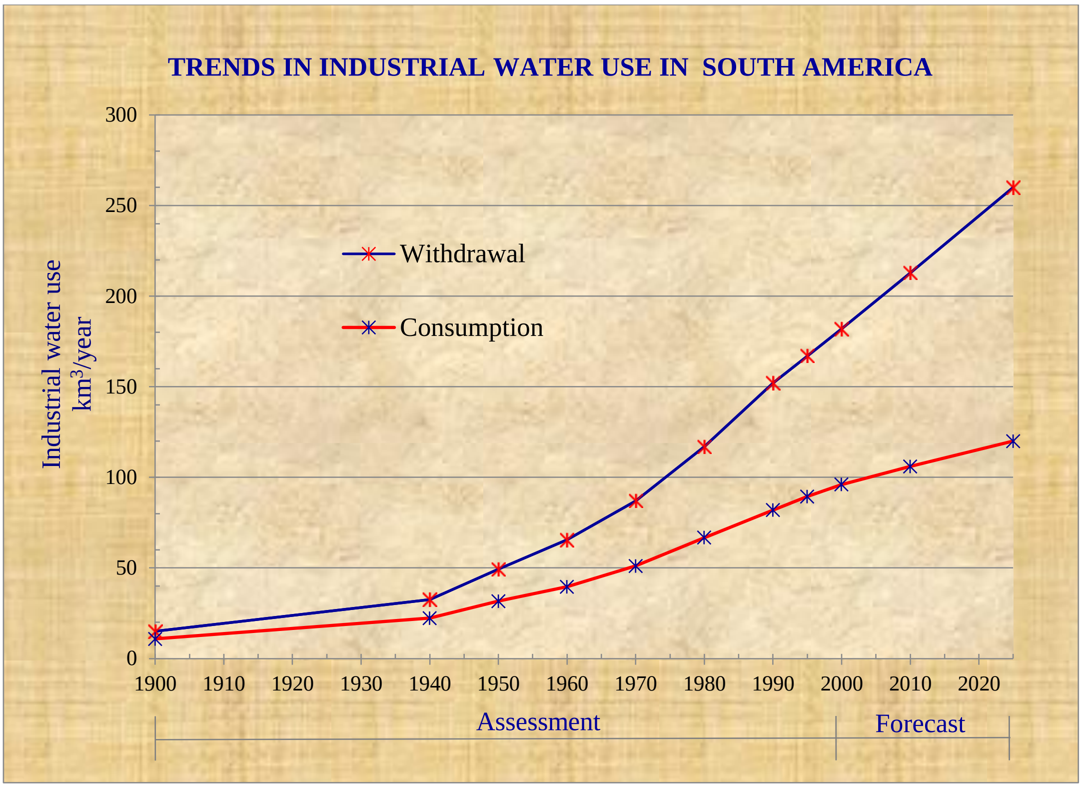

Figure 2.8: Industrial water use Trends in South America

Data Source: Shiklomanov (2002)

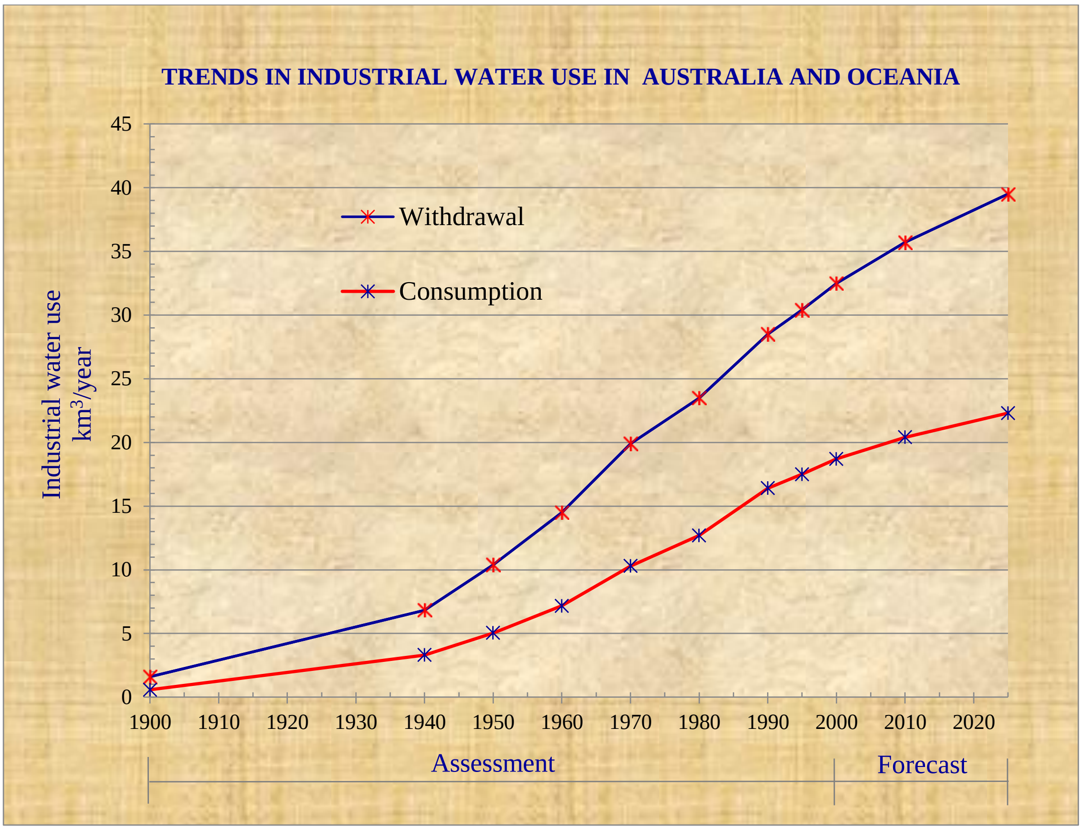

Figure 2.9: Industrial water use trends in Australia & Oceania

Data Source: Shiklomanov (2002)

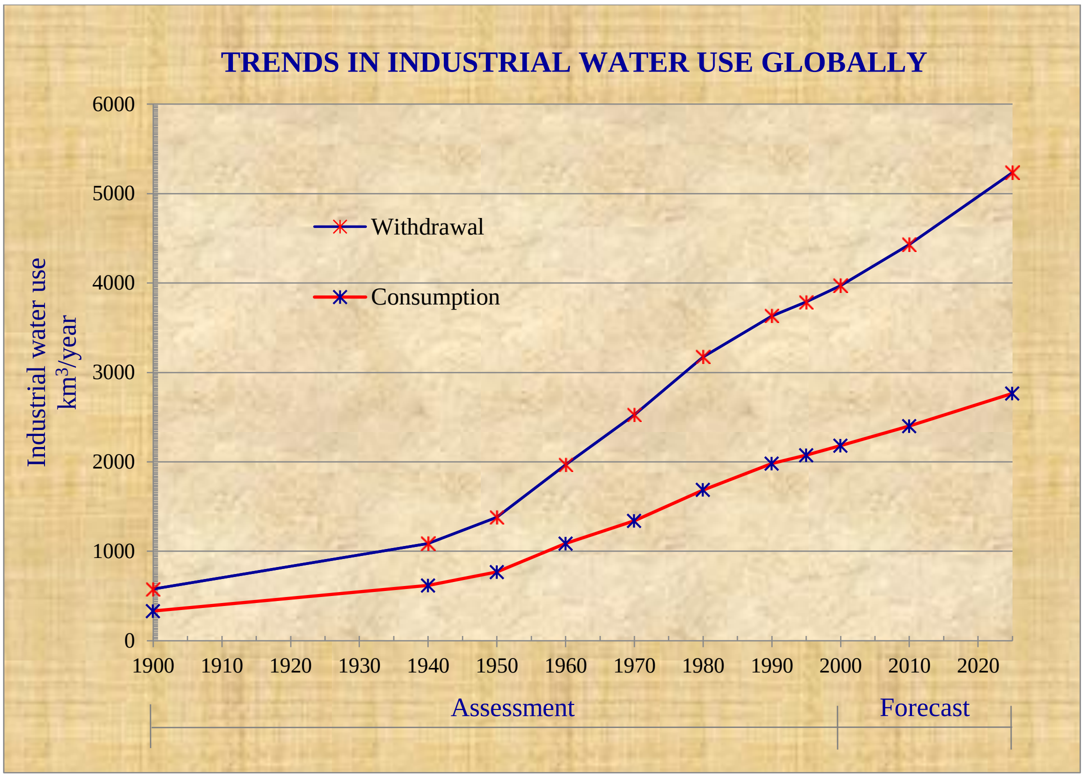

Figure 2.10: Trends in industrial water use globally

Data Source: Shiklomanov (2002)

The industrial water use graphs above depict the non – linearity of the relationship between water withdrawals and consumptions. It can be construed that the contemporary advancements in designs and operations of water facilities have led to a decline in the industrial water withdrawal in most highly industrialized countries such as Europe and North America; although, the rate of water consumption globally keeps increasing. Accordingly, water withdrawal for industrial purposes in continents with stringent regulatory regimes will continue to reduce, while in developing continents such as Africa with less stringent water withdrawal legislations, water use by industry will keep growing.

2.2.2 Industrial water use in the United Kingdom

Known as the *"forgotten utility"*, water in the UK is estimated to generate an annual bill of about £600M, with potential for 20% savings at little or no cost in sites where there has not been previous water saving efforts (Arnold and Poupart, 2013). This prevailing need for water savings and efficiency have informed the initiation of various sustainability strategies and water minimisation clubs by the UK government, aimed at promoting sustainable developments and discouraging practices that uphold water as an unlimited resource. The target of the Government has been on water intensive processes of which in the UK, the industrial sector has over decades been acclaimed the highest user of the fresh water resource. As established by World Resources Institute (1988, 1998, cited in Dupont & Renzetti 2001) 79% of water use in U.K was by industry in 1980, 77% in 1991, while subsequent findings by WBCSD and UNEP (1998) showed that UK irrigation took up 1% of the fresh water resource, 21% Domestic and Commercial, and 78% Industrial. In 2006, Food Industry Sustainability Strategy (FISS), in a bid to encourage optimal water use in the industry, challenged UK food industry to reduce its levels of water usage by setting an overall water reduction target of 20% by 2020, against a 2007 baseline (DEFRA, 2008).

EnviroWise programs have been of great help in guiding various industrial sectors on how best to minimise their water consumption, though its last publication was in 2007. Recently, the Waste and Resources Action Program (WRAP) has annually conducted econometric assessments on the use of water for non-domestic purposes which have also been targeted at reducing industrial water use especially for water intensive processes. Furthermore, in the UK, water use benchmarks are periodically reviewed and published for domestic and commercial users such as homes, schools and offices. Yet none has been published to cover the industrial sector. These gaps constitute peculiarities in UK water use by industry and call for more efforts to deduce practical water conservation measures for industrial facilities in the UK.

In every industrial sector, the importance of water is demonstrated by the growing consciousness in the quality and quantity required for its processes and applications. Drivers of the water efficiency and re-use in the industrial arena include: increase in purchase cost, high standard or quantity of water required for industrial processes and the stringent effluent discharge requirements (Ellis *et al.* 2001).

A clear understanding of water use patterns in the industrial sector requires a fore knowledge of requisite water concepts such as direct abstraction and mains water supply; water withdrawn and consumed; or consumptive and non – consumptive waters. The term *"direct abstraction"* denotes a process of directly withdrawing water from a natural source by an abstraction licence holder; this is in contrast to the *"mains water supply"* which involves delivering originally abstracted water to users by water utilities (WRAP, 2011a). Accordingly, the process of taking water from underground or diverting it from a surface source means water withdrawal; while, that *"part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock or otherwise removed from the immediate water* *environment"* is considered as water consumed (Kenny *et al.* 2005, p.47). But not all withdrawn water is consumed; water may be withdrawn, used and returned to its withdrawal point or near it with alteration in its physical, thermal or chemical properties (Glassman *et al.*, 2011) this class of water is called non-consumptive water. Conducting water conservation assessment on sectoral basis requires delineation of water consuming and non-consuming processes. Table 2.2 gives a categorisation of water uses in consumptive and non-consumptive terms.

Consumptive uses of water	**Non-consumptive uses of water**
Agriculture and irrigation	Environmental regulation
Electricity generation (as cooling)	Hydroelectric electricity generation
Industry and manufacturing	Recreation
Public water supply	Transportation

Table 2.2: Consumptive and non-consumptive uses of water

(Hall et al. 2012, p.70)

Since the non-consumptive water use principally involves water diversion and return (as in hydroelectric generation) or in-stream (typical of recreation and transportation), its water consumption is not as critical as in consumptive applications. Thus, the consumptive water processes present greater potentials for water savings; and this can be achieved through conducting accurate water use assessments and implementation of the corresponding conservation measures. To this end, the aim to optimally save water in the industrial sector will be best informed by focusing on the consumptive processes that are not just water intensive, but lead to volumetric reduction in the fresh water resource in the UK.

Water use in the UK is mainly classified under the domestic and non-domestic uses. Still focusing on the non-domestic water uses which encapsulate the industrial water uses, a recent report by Envirowise (2009, cited in Villegas and Östman, 2010) reveals that the single largest water user in the UK is the energy and gas sector, accounting for an average of 32% of the water withdrawals for non-domestic purposes. The report showed that in 2008, the sector's average water use was 12.29 l/kWh of electricity produced, excluding electricity imports. The overall water use percentages of the UK industrial sector are shown in figure 2.11.

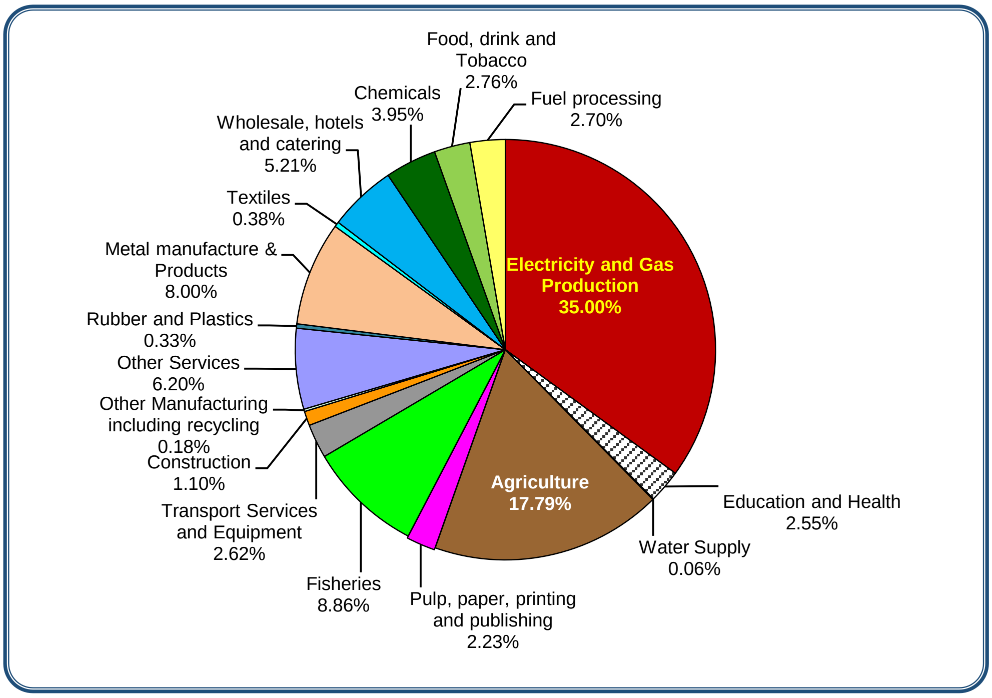

Figure 2.11: Industrial water (non-household) consumption in the United Kingdom (2008)

Envirowise (2009, cited in Villegas and Östman, 2010)

The total water consumption in the UK for non-domestic purposes in 2008 was 12,659,660 ML. This has been subdivided into percentages as revealed in figure 2.11 above. From the chart, it is evident that 35% was taken up by the electricity and gas sector, followed by the agriculture (17.79%), then fisheries (8.86%). However, most categorizations of the sectors using water in the UK separates agriculture and other agricultural processes such as fisheries, electricity and gas, and the industrial sector which is often considered as mainly the manufacturing sector.

Further, recent research by WRAP (2011a) discovered that of the total direct water abstraction for non-household purposes, the manufacturing sector was identified as the largest user, taking up between 45 – 55% of directly abstracted water volume from non-tidal sources in England and Wales, not including major non-consumptive uses. This report further revealed that the UK manufacturing sector was also recognized *"as the single largest non-household user of mains water (27% of the total volume used by non-households)"*. However, in the UK, the four regions (as detailed in figure 2.12 below) use mains water for industrial purposes in different capacities. From the charts it can be seen that in Scotland, water use for manufacturing alone accounts for 40.7% of all non-domestic water use. Further, electricity generation mains water use in all four regions remains generally low which explains the fact that water use for this purpose is mainly from abstraction. In all, mains water use for manufacturing purposes is relatively higher in three of the four UK regions in exception of Northern Ireland's mains water use which constitutes 32.6% for agricultural purposes and 23.1% for manufacturing purposes.

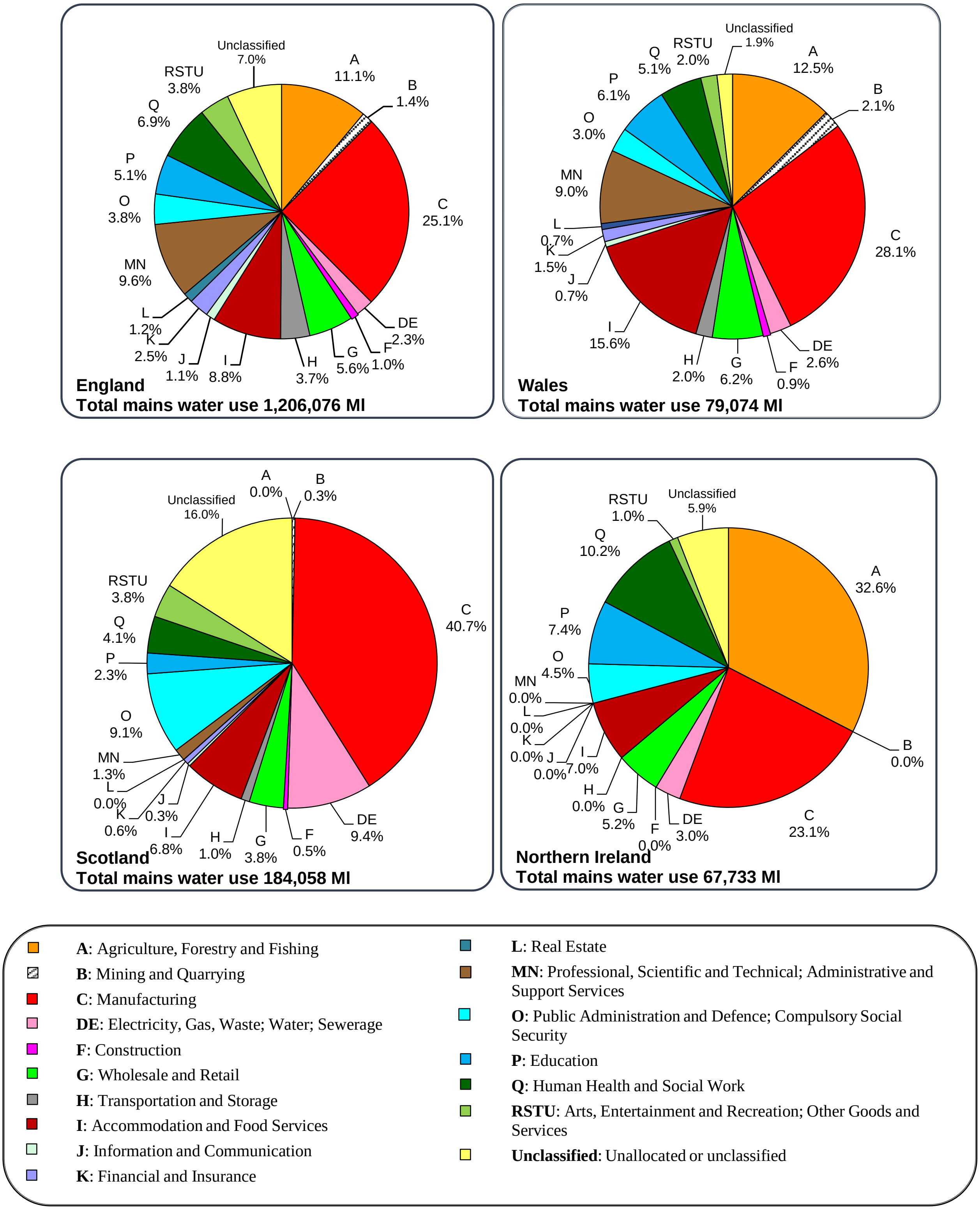

Figure 2.12: United Kingdom mains water use by region and sector (2006/07)

WRAP (2011a)

Whereas, chief sources of water for industrial processes are the mains water supply and licensed abstractions, the manufacturing sector shall be critically assessed to identify the specific high water consuming processes of the sector. More so, since direct water abstraction from the environment below 20m^3/day do not require abstraction license, this study excludes water abstractions in this category.

2.2.3 Economic activities of UK industrial sector by SIC

As defined in the report by ONS (2007, p.1), the UK Standard Industrial Classification is a system used *"in classifying business establishments and other statistical units by the type of economic activity in which they are engaged"*. This system encompasses a hierarchy of five digits, in an order of Sections, Divisions, Groups, Classes and Subclasses. The 5-digit system followed a review of the UK SIC 2003 which had *"subsection"* as the 2nd digit bringing the total number of digits to six. Hence, the UK SIC 2007 which is currently in use has the *"subsection"* subsumed mainly in the Sections and the Divisions. The complete structure of the UK SIC 2007 is comprised of *"21 sections, 88 divisions, 272 groups, 615 classes and 191 subclasses"* (ONS 2007, p.2). The 21 sections are denoted by single alphabets A – U as shown in table 2.3, while subsequent levels (Divisions, Groups and Classes) are uniquely broken down into 2 to 4 numeric digits separated by periods (.), with the last level (subclasses) separated by a stroke (/). Detailing the Manufacturing sector, a typical application of this classification method can be seen thus:

Section C — Manufacturing (covering divisions 10 to 33)
- **Division** 10 — Manufacture of food products
  - **Group** 10.5 — Manufacture of dairy products
    - **Class** 10.51 — Operation of dairies and cheese making
      - **Subclass** 10.51/1 — Liquid milk and cream production

UK Standard Industrial Classification (2007)	
Section	**Description of Economic Activity**
A	Agriculture, forestry and fishing
B	Mining and quarrying
C	Manufacturing
D E	Electricity, gas, steam and air conditioning supply Water supply; sewerage, waste management and remediation activities
F	Construction
G	Wholesale and retail trade; repair of motor vehicles and motor cycles
I	Accommodation and food service activities
H J	Transport and storage Information and communication
K	Financial and insurance activities
L M N	Real estate activities Professional, scientific and technical activities Administrative and support service activities
O	Public administration and defence; compulsory social security
P	Education
Q	Human health and social work activities
R S	Arts, entertainment and recreation Other service activities
T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
U	Activities of extraterritorial organisations and bodies

Table 2.3: 21 Sections of the UK Standard Industrial Classification (2007)

(ONS, 2011, p.2, 3)

2.2.4 Manufacturing activities of UK industrial sector by SIC

Viewing the industrial sector from the position of US WaterSense (2009, p.3) as facilities that mainly manufacture and process materials, and considering the water intensiveness of the UK manufacturing sector, a strong need arises to assess mainly the manufacturing sector (Section C), the electricity (cooling) and steam which fall under sections D and E respectively. Table 2.4 shows the diverse composition of the manufacturing sector alone.

Manufacturing section					
Sections	Subsections	Divisions	Groups	Classes	Subclasses
1	0	24	95	230	51

Table 2.4: Composition of the UK manufacturing sector by SIC

(ONS, 2011, p.2, 3)

The UK manufacturing sector is vast, comprising of 24 divisions classified under 2007 SIC section C and numbered 10 to 33 as revealed in table 2.5. With a relatively low percentage of total abstraction licenses linked with the manufacturing area, this sector generally takes up very large volumes of water for its processes. A detailed study by WRAP (2011a) revealed that out of the 13,749 licences currently held in the National Abstraction Licensing Database (NALD), 1,040 were associated with the manufacturing sector. According to the author, these 1040 licences (8% of the total) constitute between 48% - 62% of total non-households water use and exclude the large non-consumptive uses.

SIC2007 (Section)	SIC2007 (Division)	Description
C	10	Manufacture of food products
C	11	Manufacture of beverages
C	12	Manufacture of tobacco products
C	13	Manufacture of textiles
C	14	Manufacture of wearing apparel
C	15	Manufacture of leather and related products
C	16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
C	17	Manufacture of paper and paper products
C	18	Printing and reproduction of recorded media
C	19	Manufacture of coke and refined petroleum products
C	20	Manufacture of chemicals and chemical products
C	21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
C	22	Manufacture of rubber and plastic products
C	23	Manufacture of other non-metallic mineral products
C	24	Manufacture of basic metals
C	25	Manufacture of fabricated metal products, except machinery and equipment
C	26	Manufacture of computer, electronic and optical products
C	27	Manufacture of electrical equipment
C	28	Manufacture of machinery and equipment n.e.c.
C	29	Manufacture of motor vehicles, trailers and semi-trailers
C	30	Manufacture of other transport equipment
C	31	Manufacture of furniture
C	32	Other manufacturing
C	33	Repair and installation of machinery and equipment

Table 2.5: 2007 SIC structure for manufacturing activities: division codes and description

WRAP (2011a)

2.2.5 UK Manufacturing sub-sectors' water use intensities

Past studies on the sectoral use of water on regional basis have revealed that out of the three UK environmental regulators (Environment Agency, SEPA and NIEA), water abstraction data is only obtainable from the Environment Agency as extracts from the National Abstraction Licensing Database (NALD) (WRAP, 2011a; 2011b). These data have been used to assess the water consumption rates of the manufacturing subsections (as outlined in table 2.5) and has helped in revealing processes that are highly water intensive. The most recent study on the use of water by the manufacturing sector was conducted in 2011 and involved the use of the available dataset (2006), covering the region with the largest population and geographic area of UK - England and Wales. Figure 2.13 thus shows a detailed graphical representation of the industrial water use by major divisions of the manufacturing sector. The assessment was conducted in terms of the upper and lower bound estimates of industrial water consumptive uses. The upper bound consumptive use was considered as the difference between the total volume abstracted and the volume for major non-consumptive uses (volume for abstraction returns with no non-consumptive use associated with them); whereas, the lower bound consumptive use was classified as having at least one non-consumptive use associated with its volume for abstraction return (WRAP, 2011a).

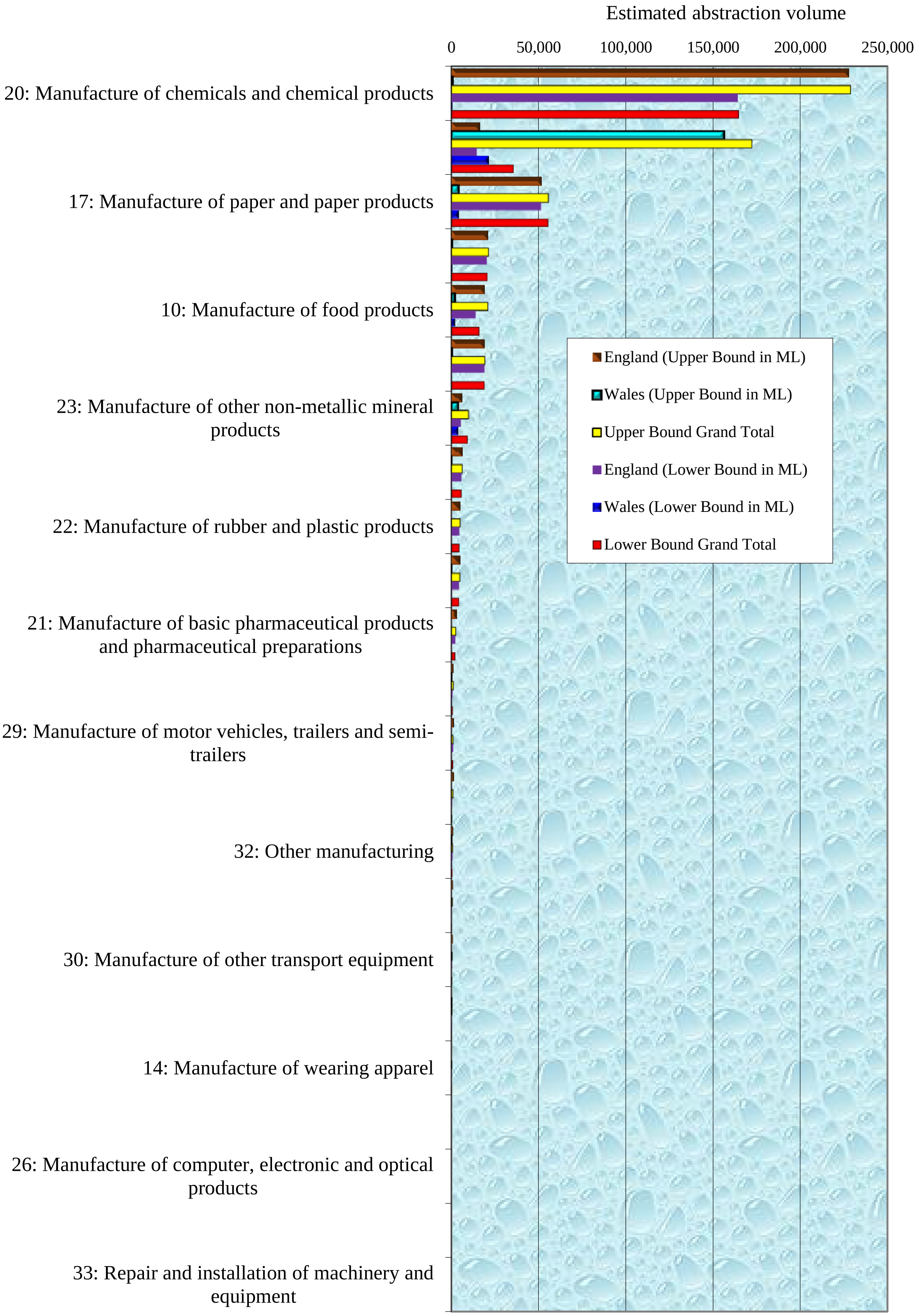

Figure 2.13: Estimated volume directly abstracted for manufacturing purposes from non-tidal sources in England & Wales by sub-sector classification (divisions for SIC section C)

Data Source: WRAP (2011a)

Results of the investigation by WRAP (2011a) represented in figure 2.13 revealed that in terms of water volume directly abstracted in England, the division or sub-sector with the largest water consumption is the *"Manufacture of chemicals and chemical products"* (2007 SIC division 20), accounting for more than one-half or approximately 56% of the total water directly abstracted by the manufacturing sector for consumptive uses. The next water intensive subsector for the year under review (2006) was the *"Manufacture of paper and paper products"* (2007 SIC division 17); both subsectors used up circa 70% of the total water volume directly abstracted for consumptive use by the manufacturing sector in England (WRAP 2011a). This condition contrasts with the manufacturing sector water use trends of Wales where the *"Manufacture of basic metals' sub-sector (2007 SIC division 24)"* alone accounted for 73% of total volume directly abstracted for consumptive purposes in the manufacturing sector.

From the report, it is identified that in England and Wales, the top five water intensive manufacturing subsectors are: Manufacture of chemicals and chemical products (SIC division 20); Manufacture of basic metals (SIC division 24); Manufacture of paper and paper products (SIC division 17); Manufacture of beverages (SIC division 11), and Manufacture of food products (SIC division 10).

Further assessment into the sub-processes of these key water users in the industrial front will help reveal specific water intensive processes and deduce potential water conservation measures. This assessment shall cover the water use from both direct water abstractions and the mains water supply in the four regions of the UK: England, Wales, Scotland and Northern Ireland.

2.2.6 Water use by specific industrial subsectors

When aggregated, water use by industry is relatively large; however, water demand varies from one industrial sector and process to another. With the industry's varied processes across a range of subsectors, an effective way of achieving water saving is through assessment using water per unit of each product (Seneviratne, 2007). This value is often both site and country-specific. Major reasons for variation in water use per product include the technology in use, the availability of the water resource and the state of the raw material used for specific processes. Table 2.6 reveals water usage per unit product in selected European Union countries; although, variations in data collection mode remains inexcusable, but the values shown in the table supports the argument that even among developed countries, there are great prospects of water minimisation per unit product of industrial processes.

Country	1 L of beer	1L of milk	1kg of cloth	1kg of paper	1kg of steel	1kg of sugar
Austria	10	5	n/d	150	15	15
Denmark	3.4					
France	25	1–4	n/d	250–500	300–600	21–35
Ireland	8				4.5	
Norway	10	1–1.5	130 (all kinds)	20	30	n/d
Spain	6–9	1–5	8–20 (wool)	250	30	3.5–5
Sweden	3–5	1.3	40–50	20	0.6–5.3	0.5
United Kingdom	6.5 (estimated range 2–10)	2.9	6–300 (depends on the type of fabric)	15–30	100	1.5 (estimated range 0.7–6 L)

Table 2.6: Water usage per unit product in selected European Union countries

Source: European environment agency (1999)

Based on table 2.6 above, it is striking how 1 L of milk is produced using 5 L of water in Austria while same volume of milk is produced using about one-fifth of Austria's 5 L in countries like France, Norway and Spain. Accordingly, 1kg of steel which is manufactured in the UK with 100 L of water is also manufactured in Sweden using 0.6 – 5.3 L of water (circa one-hundredth of UK water volume). Apparently, potentials for significant water savings exist in different countries depending on the water intensities of their processes and products, and relative to those of other countries.

Granted that a focus on major water intensive processes in the industrial sector will help in revealing areas of significant water saving opportunities, from the foregoing, in addition to the use of water for power generation which constitutes the highest water user in UK, the five manufacturing subsectors with the largest water usage (Chemicals, Basic metals, Paper, Food and Beverages) will be detailed in the succeeding sections.

2.3 Manufacture of Food Products and Beverages (SIC Division 10 & 11)

Contributing circa £26.4bn in Gross Value Added (GVA), the UK food and drink sector is currently the largest manufacturing sector in economic terms and one of the few sectors which economically kept growing throughout the period of economic downturn (DEFRA, 2012a). Considered as a major user of water both through mains water and direct water abstraction, this sector greatly contributes to the growing demand placed on the existing UK fresh water resource. Estimates show that food and drink manufacturing alone uses about 190 million m^3 per year of water, of which 78 million m^3 is directly abstracted (WRAP, 2013b).

Water plays a very significant role in the food and beverages manufacturing processes; it is used for a wide range of activities such as transporting, cleaning, washing, processing, blanching, formulating products, peeling, mixing, steam generation, freezing and for purposes of hygiene. A key peculiarity associated with the sector's water demand is the high quality of water required for its processes. In order to meet regulatory standards and ensure the manufacture of hygienic products, the food and beverage sector heavily relies on main water for most of its water needs. However, in the past decade, there has been a decline in mains water use in this sector and a rise in the water abstraction from rivers and underground sources. This has been attributed to the high and growing cost of purchasing water from the water companies (IGD, 2007).

It is important to state that although the Standard Industrial Classification considers Beverages, not Drinks, as a discrete sector, use of the terms Beverages and Drinks is highly contextualized. In the UK, Beverages is a subsector of the Drink sector while in the United States these are separate infrastructure regimes. However, since this study is UK specific and for purposes of consistency, Drinks will be used as the umbrella sector, while Beverages will be subsumed under this Drinks sector. Table 2.7 reveals the corresponding divisions of the UK Food and Drinks sectors.

Food sub-sectors	Drink sub-sectors
Bakery Cereal products	Soft drinks and beverages
Confectionery Dairy	Brewing
Animal feed Fish processing	Distilling
Fruit and Vegetables Meat processing	Wine
Milling Pet food	Cider
Pre-prepared foods	Maltings

Table 2.7: Food and drink manufacturing sub-sectors

Source: WRAP (2013b)

2.3.1 Food processing sector

The majority of water used in the food processing industry is for washing of food, pasteurization, cleaning of equipment, food preparation (cooking), steaming and sterilization; or as an additive or stabilizer in canned fruit or vegetable (David, 1990); these activities constitute process water and are areas potential water conservation. As shown in figure 2.14, process water accounts for the largest water use in the food sector.

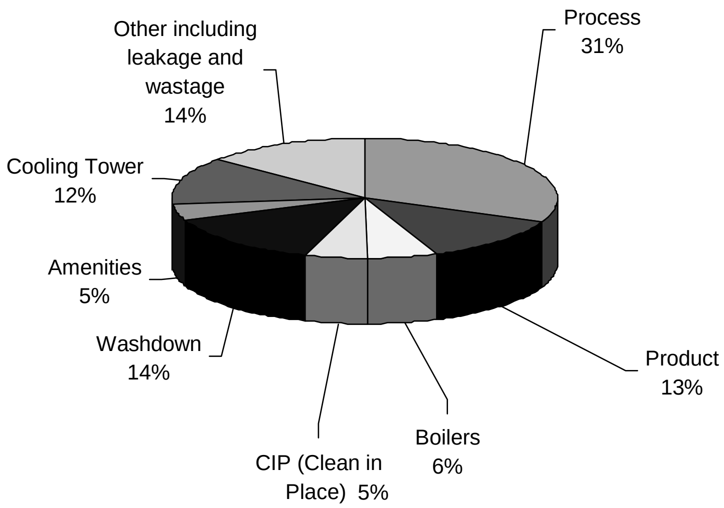

Figure 2.14: Water use breakdown in a typical food manufacturing sector

Source: Ellis et al. (2001)

Although water use in this sector can be generally classified to reveal the most water intensive processes as shown in figure 2.14 above, but different food manufacturing processes require unique water quantities for specific tasks and these vary significantly. In producing sugar, it has been discovered that about half of the intake water is basically used for cooling while about 20% or less is actually used for processing (Ellis *et al.,* 2001). In contrast, "*for meat processing and fruit preservation, about 60% of the intake water is used as process water*" (David 1990, p.89).

It is also worth stating that water use requirements vary depending on both the food processing sector and its constituent's end products. Table 2.8 provides estimated water demands for processing some selected major foods as observed in a cognate study by Rogers (1993, p.34) and David (1990, p. 89).

Product	Water Use (L/L or kg - product)
Beer	9.08 - 14.54
Milk products	9.08 - 18.17
Meat packing	13.63 - 18.17
Bread	1.82- 4.36
Whisky	54.51 - 72.68
Green beans (canned)	45.42- 64.35
Peaches and pears (canned)	13.63 - 18.17
Other fruits and vegetables (canned) Industry-wide average	4.36 -31.80
Industry-wide average	0.15 L/unit output

Table 2.8: Food processing water needs

Adapted from: Rogers (1993, p. 34) and David (1990, p. 89)

2.3.2 Beverages manufacturing sector

In the beverage industry, clean and high-quality water is an essential ingredient for all products (BIER, 2012). Although major products and processes of this subsector include Spirits, Soft drinks, wine, cider, brewing and malting (WRAP, 2013b), Beverage Industry Environmental Roundtable (2012), considers four main types of beverage production facilities: bottling, brewery, distillery and winery.

i. Bottling

This involves blending water with concentrate, syrup, flavours / infusions, and or bulk alcohol, and packaging same into various container types; or *"facilities which receive finished bulk product (such as completely brewed beer or matured whiskey)"* (BIER, 2012). These facilities therefore do not ferment or distil. In a recent research conducted by BIER (2012) on 1,481 facilities spread across six continents, it was discovered that even as 69% of the data collected were from the bottling sites, bottling facilities generally used the least amount of water to produce a litre of product, given that there are fewer water-intensive processes in this subsector as compared to the brewery, distillery, and winery facilities.

ii. Brewery

This is defined as facilities that conduct all processes after the malting process to produce beer (BIER, 2012). These processes according to the author include mashing or lautering, boiling, fermenting, aging, and packaging. From separate reports by EA (2013) and the BIER (2012) water use in this sector has been on the decline over the past few years following the application of more water efficient technologies and practices. In the report by BIER (2012), it is noted that of the assessed 296 breweries, 83% showed an improvement in water use ratio from the year 2009 to 2011. Particularly, the report noted that there was a 12% improvement in water use ratio for breweries that produce beer only; this it remarked as the greatest improvement over years.

iii. Distillery

This is defined as *"any facility that receives agricultural inputs (grains, agave, molasses, etc.) and conducts processes (cooking, fermenting, distilling and storage/maturation) to make bulk alcohol"* (BIER 2012, p.9).

In terms of water use in this sub-sector, a recent report by the Environment Agency (2013) showed that distilleries used the highest water for its processes. In particular, manufacturing spirits was identified as the most water intensive activity. Also, results of a study by WRAP (2013b) on water use in the beverage industry revealed that in both 2007 and 2010, water use in distilling Spirits remained the highest (see figure 2.15 below). It is pertinent to state that Spirits which have very high ethanol content require greater water to distil and for cooling the production equipment. As noted by BIER (2012) alcohol content is a key reason behind the high water use intensities in distilleries.

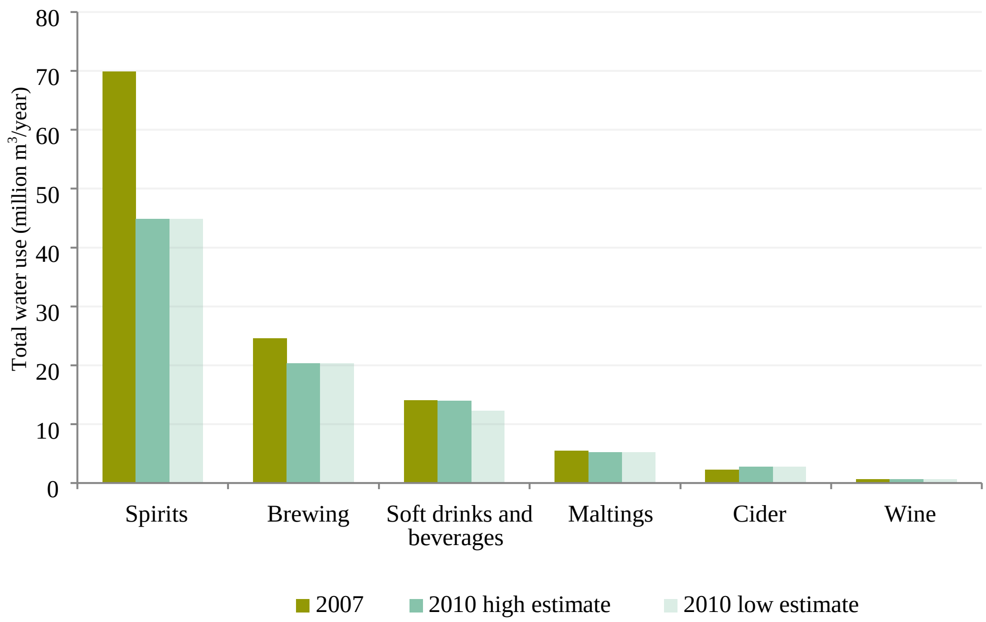

Figure 2.15: Sub-sectoral breakdown of water use in the UK drink industry

Adapted from: WRAP (2013a)

In 80 facilities investigated by BIER (2012), it was revealed that even with a 54% improvement in the constituent water use ratio from 2009 to 2011, distilleries had the largest water intake. As inferred in the report, a major driver behind the high volume of water use in this subsector is the extensive cooling water requirement of distilleries; this is exacerbated by the use of once – through cooling system.

iv. Winery

The major winery processes as noted by Beverage Industry Environmental Roundtable (2012) include: *"the crushing and pressing of grapes, fermentation, storage/aging and bottling of product"*. Further, key water intensive areas/processes in this subsector are fermentation tanks (both primary and malolactic fermentation), bottling lines, barrel washing and soaking, barrel soaking, equipment cleaning and the crush pad (Galitsky *et al.*, 2005). Globally, water use in wine making is relatively high. Results of an investigation by BIER (2012) on 27 winery facilities over a period of three years showed that winery is the only major beverage type with a remarkable increase in water use ratio from 2009 to 2011, yet with a 25% decrease in production.

Figure 2.16 gives an illustration of the key steps requiring water of different intensities in the four major facilities of the Beverages manufacturing sector.

Figure 2.16: Process maps of four main types of beverage production facilities: bottling, brewery, distillery and winery.

Source: BIER (2012)

2.3.3 Water use steps and percentages in beverage manufacturing processes

A clear understanding of key water intensive processes is crucial to any measure to conserve water in the beverage or drink sector. As revealed in table 2.9 below, evaluating the case of carbonated soft drinks, the process water use percentage is over ¾ (78%) of the total water used in manufacturing the product. In the same vein, equipment preparation requires about 67% of the total water intake for bottling processes. These water intensive areas have potentials for the greatest water conservation and should be the main target of any water reduction strategy.

Type	Water use steps
Bottled water	• Rinsing (2%) • In product (30%) • Equipment preparation (67%) • Domestic use (1%)
Fruit Juice	• In product (27%) • Equipment preparation (51%) • Floor washing (3%) • Boiler water (11%) • Pasteurizers (4%) • Cooling water (4%)
Carbonated soft drinks	• Rinsing of containers (4%) • In product (78%) • Equipment preparation (3%) • Floor washing (1%) • Boiler water (4%) • Pasteurizers (6%) • Domestic use (3%) • Other uses (1%)
Wine	• In product • Cooling • Equipment preparation • Vessel washing
Juice Concentrate	• None currently identified

Table 2.9: Beverage subsectors' water use steps and percentages

Adapted from: Environment Agency (2003, p. 11)

2.3.4 Most water intensive food and drink subsectors

According to the Environment Agency (2013), *"water use for food and drink manufacture represents 56% of total water use by the industry"*. In 2010, estimates of total water use in the food and drink sector was between 347 million m^3 and 366 million m^3, which represents a reduction of about 15.6% of 2007 figures (EA, 2013); figure 2.17 illustrates how water in this sector was used by the corresponding subsectors in the two years under review, 2007 and 2010.

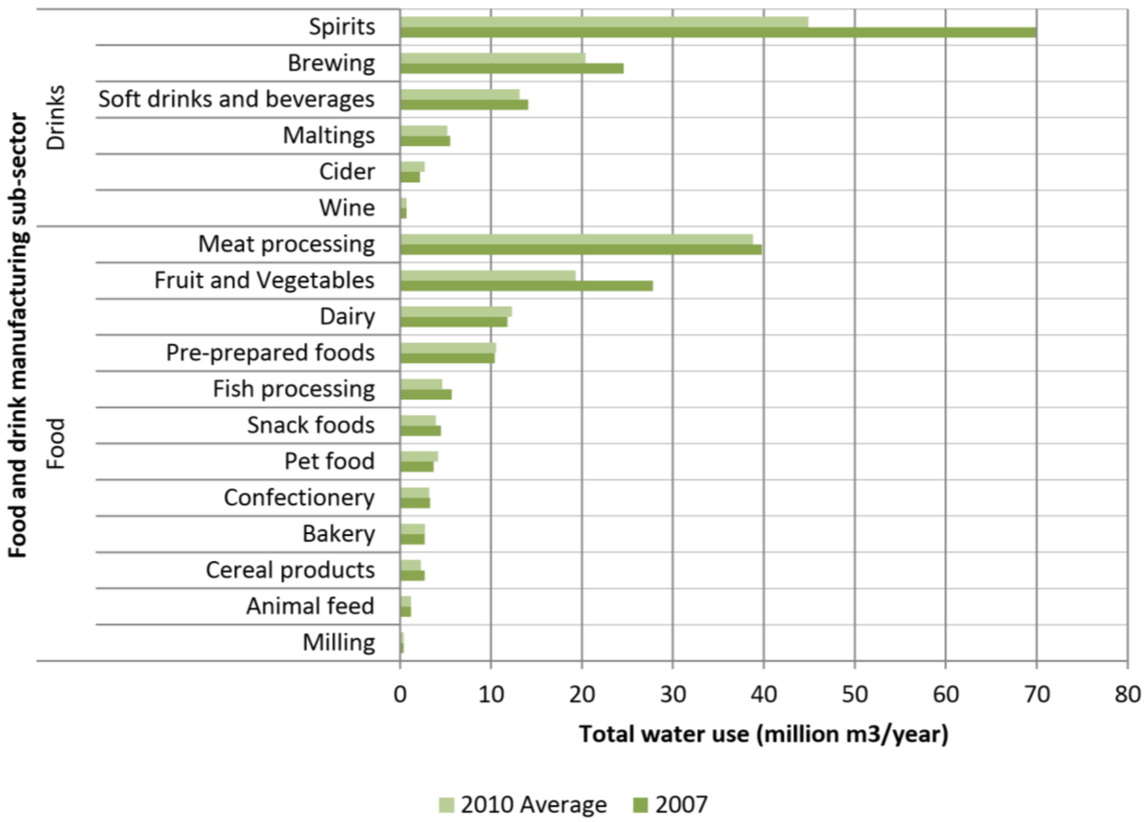

Figure 2.17: UK food and drink manufacturing sub-sectors' water use (million m^3 per year).
WRAP (2013b)

In figure 2.17, five most water intensive food and drink subsectors can be seen. In the food sector, meat processing used the largest water in both 2007 and 2010, each totalling almost 40 million m^3/year; with a marginal drop in 2010 relative to the year 2007. With a near 30% decline (45 – 70 million m^3) in its water use between 2007 and 2010, spirits constituted the highest water user for both the drink and food subsectors. From the above figure, top five most water using subsectors are identified; this is revealed in table 2.10 in an order of descending water use.

	Total Water Use	Water use excluding that in product
1	Spirits	Spirits
2	Meat processing	Meat processing
3	Brewing	Fruit and vegetables
4	Fruit and vegetables	Brewing
5	Soft drinks and beverages	Dairy

Table 2.10: Top five water-using food and drink manufacturing sub-sectors in the year 2010
Adapted from: WRAP (2013b, p. 7)

2.3.5 Barriers to water savings in the food and beverages sector

According to the Institute of Grocery Distribution (2007) setting benchmarks and monitoring water reduction targets in the food and beverage industry has been difficult, given the large variation in water use across the products. In discrete terms, major barriers to water savings in this sector have been identified by FISS (2007) to include but not limited to the following:

1) Lack of data to enable technical and economic assessments.
2) Low patronage of relevant equipment to sub-meter water use for proper water accounting.
3) Uncertainty about financial gains.
4) Stringent products' quality requirements.
5) Unaffordability of requisite tools and technology.

2.3.6 The UK food and beverages water reduction progress to date

In a bid to address the aforementioned water concerns, the Food Industry Sustainability Strategy group on water recently challenged food and beverage industry to reduce its water use by 2030 against a 2007 baseline; this reduction excludes embedded water in products. Consequent upon this target, the Federation House Commitment (FHC) which is a voluntary agreement was developed to assist food and drink companies reduce water use across their individual manufacturing sites (FHC, 2013). Managed by WRAP, the FDF, Dairy UK and the Environment Agency, and administered by Hyder Consulting, the FHC has registered a significant number of signatories accepting to strive towards achieving this target. As revealed in the FHC website, as at March 2014, 70 signatories across 284 active sites have signed up to the commitment (FHC, 2013).

Following the huge subscription to this target, between 2007 and 2012, data collected from 250 sites were analysed; results of this exercise revealed a 16% absolute reduction in the water use, corresponding to 7.4 million m^3 or an equivalent of 2,965 Olympic-size swimming pools (FHC, 2013). It is also impressive to note that during this period, production across the examined sites increased by 6.1%. These results are revealed in figure 2.18 below. In the diagram, data for 2007, 2011 and 2012 were plotted, for the remaining years (2008, 2009, 2010) their water use and production performance were interpolated and revealed in broken trend lines.

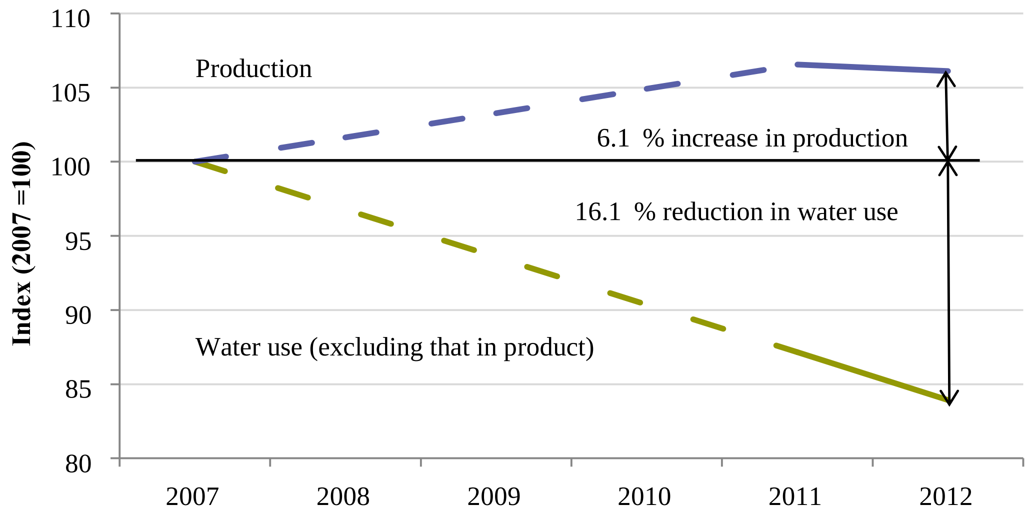

Figure 2.18: Water use and production trends in the UK food and drink sector between 2007 and 2012

Source: FHC (2013)

2.4 Manufacture Of Chemicals and Chemical Products (SIC Division 20)

The chemical sector is a vast industry that manufactures items ranging from basic acids and base to complex products (Pollak, 2007); these products provide building blocks or fundamental materials used in other industries (Byers, *et al.*, 2003). In the opinion of Bowman (1998 cited in Ellis *et al.*, 2001) the industry is so large and varied that any generalization about its water use cannot be considered credible. Accordingly, authors have variously posited that water consumption data in the chemical industry remains relatively scarce; this makes it difficult to identify most water intensive chemical products (EC, 2009 & Byers, *et al.*, 2003). A good understanding of the water use intensity of the chemical processing industry (CPI) is best informed by assessing its subsectors and constituent products. According to Pollak (2007), there are three major subsectors of the CPI, they include: fine chemicals, commodities and specialty chemicals.

2.4.1 Fine Chemicals

As noted by the Department of the Environment Industry Profile (1995) the historical antecedent of fine chemical manufacturing industry in UK is closely linked to the advent and development of synthetic dyes for the textile industry in the 19th Century. It is recorded that during the 1850s, chemists working with coal tar distillates synthesised the first synthetic dyes. Subsequently, further research into potentials of dyes resulted in the synthesis of a wide range of complex organic chemicals and emergence of fine chemicals. Notable is the ICI Pharmaceuticals in United Kingdom which evolved out of the Dyestuffs Division of that company (DEIP, 1995).

Fine chemicals are chemicals manufactured to high and precise standards of purity (DEIP, 1995). Thus, they are single, complex and pure chemical substances manufactured in very limited quantities (<1000 metric tons/year) (Pollak, 2007). They comprise of dyestuffs, photographic chemicals, high purity laboratory gases, pigments and their intermediates, food additives, vitamins, pharmaceutical active ingredients, laboratory reagents, perfumes and pesticides (DEIP, 1995). It is important to note that these products of fine chemicals constitute the building blocks for specialty chemicals.

2.4.2 Commodity chemicals

In the opinion of Pollak (2007), commodity chemicals or commodities, by definition, are low-price, high-volume, homogeneous and standardized chemicals manufactured in dedicated plants and used for a wide range of applications. According to the author, products in this category include: commodity fibers, plastics, petrochemicals, basic chemicals, heavy organic or inorganic chemicals (large-volume) monomers, ethylene, poly (vinyl chloride) soda, caprolactame, sulfuric acid, BTX (benzene, toluene, xylenes) and methanol.

In practice, there is an existing difficulty in distinguishing between fine chemicals and commodities. Although Pollak (2007) claims that the major distinction between both products is that in wider terms, fine chemicals are manufactured by chemists; whereas, commodities are produced by chemical engineers. In terms of branding, marketers prefer using the designation of fine chemicals merchants than using commodities, as they contend that the former has the bigger market and especially as it is the basic component for the manufacture of both commodity and specialty chemicals.

2.4.3 Speciality chemicals

Clearly defined by Pallock (2007), specialty chemicals are chemical formulations containing one or more fine chemicals as active ingredients. Subcategories of the speciality industry in the view of the author include agrochemicals, electronic chemicals, catalysts, enzymes, flavors, fragrances, biocides, food and feed additives, adhesives, and specialty polymers.

In principle, the difference between the fine and specialty chemicals as conceded by Pallock (2007) is that fine chemicals are retailed based on *"what they are"*; whereas, specialty chemicals are considered on the basis of *"what they can do." For instance, "in* *the life science industry, the active ingredients of drugs are fine chemicals, the formulated drugs, specialties"* (Pallock, 2007).

2.4.4 Water use intensity in the Chemical Industry

Basically water use in this sector is divided into three: within the chemical product, as a raw material – for blending and dilution; during the manufacturing process - for heating, cooling and vacuum systems; outside the manufacturing process - for vessel washing and other general cleaning (Environmental Technology Best Practice Programme Guide, 1997). However, in a study conducted by Ellis et al., (2001), it was inferred that the most predominant use of water in the chemicals industry is for cooling; this is so because chemical reactions generate great amount of heat, thus chemical reaction temperatures must be contained within desired limits so that they do not get out of control (David 1990, p. 84).

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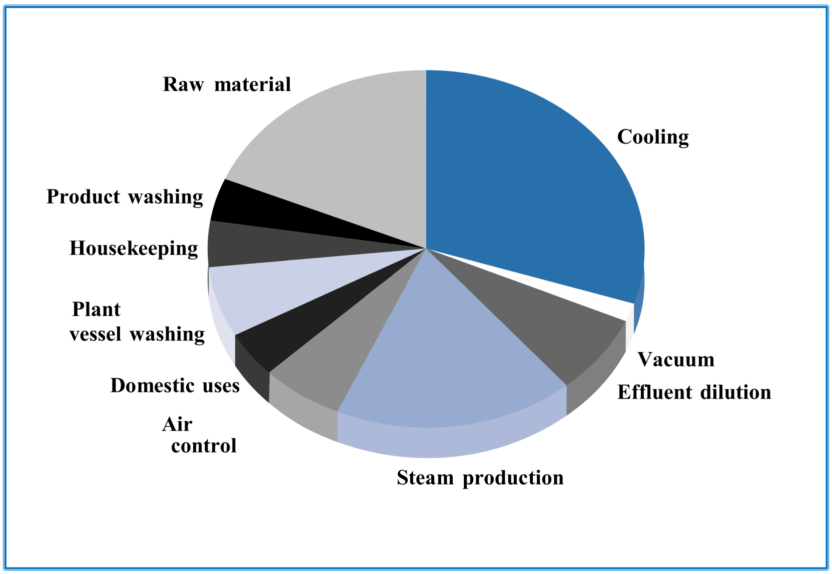


Figure 2.19: Major uses of water in the speciality chemicals sector

ETBPP (1997)

In a survey conducted by ETBPP (1997) on 47 chemical industry sites in the UK, a typical rate of water use in this sector was obtained. A summary of the result is as revealed in figure 2.19. The pie chart shows that cooling remains the highest water user in the chemical industry, closely followed by water use as raw material for chemical manufacturing processes, then steam production.

From the foregoing, the chemical industry is a relatively diverse sector with vast products, and an understanding of the water intensiveness of these products is key to any measure to minimise water use in this sector. A comprehensive research by the UK Environment Agency (2003) shows the exact water implication of manufacturing a range of the chemical products. This is revealed in table 2.11 below.

Product Type		Units	SWC (Specific Water Consumption) Typical/Range
Resins, adhesives, detergents, disinfectants, photographic solutions		m^3/t	<1.0[1,2]
Sulphonic Acids, detergents, rubbers, resins, pigments, salts		m^3/t	1 – 2[1,2]
Silicones, Polyacrylics, water treatment chemicals, chelating agents, surfactants, amine products, synthetic organic polymers, sulphonic acids, esters, imides, anhydrides, quaternaries, alkyl ethers, salts, soaps		m^3/t	2 – 5[1,2]
Brightening agents, dyes, biocides, herbicides, insecticides, phosphates, pharmaceutical, intermediates, polyacrylics, amine products, esters, soaps		m^3/t	5 – 10[1,2]
Esters biocides, fungicide intermediates, mercaptan gas, odorants, carbonates, thioglycollates, thioureas		m^3/t	10 – 50[1,2]
Pharmaceutical intermediates, acrylates, amine products		m^3/t	50 – 100[1,2]
Liquid Crystals, buffer solutions, pigments, chlorine and bromine products [1,2]		m^3/t	>100[1,2]
Chloro-alkali industry	Amalgam, diaphragm and membrane processes	m^3/t	1 - 2.8[3]
	Brine re-circulation process	m^3/t	2 - 2.5[3]
	Waste brine process	m^3/t	10[3]

Table 2.11: Specific Water Consumption intensities of some specialist chemical products

Source: [1]ETBPP (1997); [2]Mathieson et al., (2010) and [3]European Integrated Pollution Prevention and Control Bureau (2000), cited in Environment Agency (2003, p. 24)

2.5 Manufacture Of Paper and Paper Products (SIC Division 17)

2.5.1 Overview of pulp and paper products

Subsumed under the broad category of *"Forest Products Industry"*, the pulp and paper manufacturing industry is the only sector with a large and *"peculiar"* water use profile. In the United States, forest products (pulp and paper) industry constitutes the largest industrial process water user (EPA, 1995). The peculiarity attached to the sector's intense water demand is attributed to the inalienable affinity of its process for sufficient water. As remarked by Olejnik (2011), it is both environmentally and economically justifiable to minimise water use in the paper and pulp sector; however, closing the water loop in this sector has significant negative implications on various technological operations and the product quality. These effects are detailed in the subsequent sections.

With its raw materials sourced from trees and recycled fibre, products of the paper and pulp industry include (but not limited) to paper, lumber, fuels, board products, landscape materials, engineered wood products and many other speciality items (Byers, *et al.* 2003). As detailed by these authors, hundreds of paper products are manufactured in this industry, with varying degrees of strength, brightness, colour, absorbency, permanence, printing qualities and other physical characteristics. It is worth noting that requirements of the final product inform the pulp type to be used: wood pulp used for the production of shopping bags and corrugated boxes is not bleached; whereas, bleached pulp is used in the manufacture of copy paper, magazine stock, newsprint and book grades (Byers, *et al.* 2003). However, manufacture of these paper products from both bleached and unbleached pulp entails processes with varying water intensities. This is also discussed in details in the succeeding section.

2.5.2 Specific water use intensities in Pulp and Paper Manufacture

As earlier highlighted, water is an indispensable resource in the pulp and paper industry. It plays a crucial part in transportation of fibres, cleaning of equipment, cooling, lubrication, and in regulating products' quality (Olajnik, 2011). Further, three additional roles of water in the pulp and paper industry have been identified by Byers, *et al.* (2003) to include: making up process chemicals, separating and purging contaminants from products and removal of heat from the system and processes.

In terms of water use in the industry, this is measured as a unit of the product manufactured. For specific water uses, the following terms according to Byers *et al.* (2003) are adhered to: Pulp production is expressed in cubic meters per oven dry metric ton (m^3/odt) or cubic meters per air dry metric ton (m^3/adt) (note that an air dry ton actually contains 10% moisture), whereas, water used in papermaking is expressed as a unit of actual product weight, without respect to moisture content – cubic meter/metric ton (m^3/t).

According to the Environment Agency (2003) the key water use steps in this sector include: water for pulping – debarking, mechanical pulping, chemical pulping, bleaching; and for papermaking: de-inking (wastepaper only), steam raising and cooling process. Summing up the water use intensities of these processes under the key subsectors (Pulping and Papermaking), reveals that the largest amount of water is used up during the manufacture of pulp (45%), while the papermaking machine takes up the second share (35%) as revealed in figure 2.20 below.

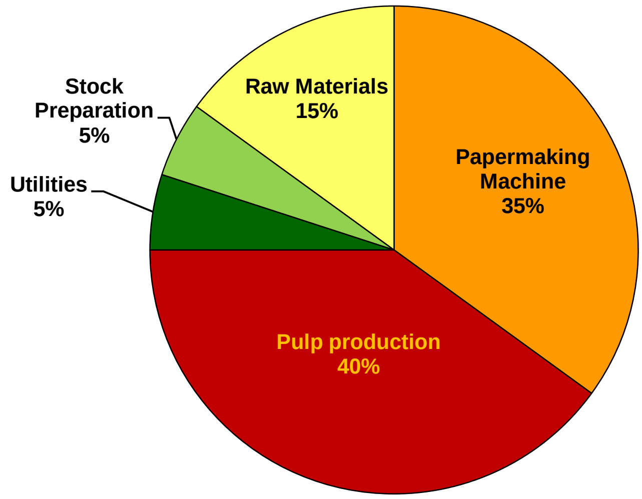


Figure 2.20: Step-wise fresh water use in pulp and paper production

Adapted from: Olejnik (2011)

Further, although papermaking machine takes up as much as is revealed in figure 2.20, manufacture of different paper grades require different water use levels (see table 2.12) and specific quality requirements. This also implies that not all available water can be directly used.

Paper grade	Fresh water consumption ($m^3\ t^{-1}$ of paper)
Tissue	5–30
Printing and writing	10–50
Specialty	20–80
Newsprint	15–30
Packaging (virgin and recycled pulps)	6–45
Corrugated boards	6–40

Table 2.12: Water requirements of different paper grades

Source: Olejnik (2011, p. 116)

2.5.3 Consequences of water reduction in Paper Mills

High temperatures of process water and increased concentration of dissolved and suspended solid materials in the paper machine are major results of reducing water use in pulp and paper making. These often give rise to complications in the paper machine run ability, general product quality compromise and particularly, paper defects (Olejnik, 2011). Concentration of the dissolved substances is increase with the recirculation of water which is a major water conservation scheme in the pulp and paper sector. Thus, strategies of water minimisation in pulp and paper production are very complex, and mainly rely on the water loop closure which in turn is informed by the required paper quality, raw materials used, equipment type, chemical additives and staff expertise (Olejnik, 2011). The trend line in the graph (figure 2.21) shows that the highest concentration of dissolved substances (2,000 – 2,500ppm) falls between 2 - 5 m^3 of water use per tonne of production.

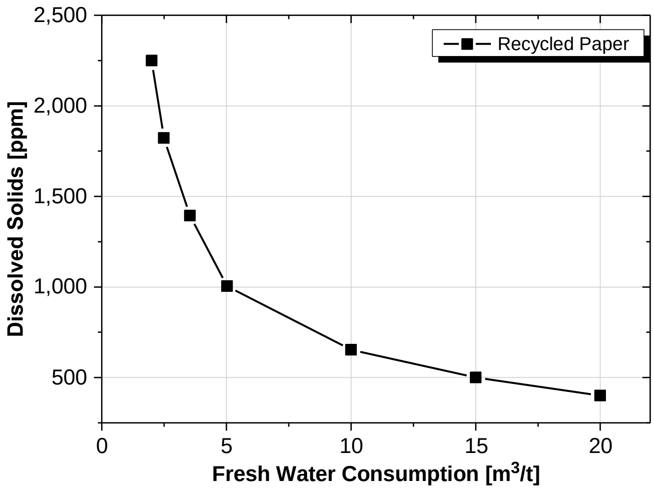


Figure 2.21: Accumulation of substances dissolved in paper mill circulating water

Adapted from: Olejnik (2011)

One advanced method of enhancing the performance of paper processes in terms of water use rates is through the use of Control performance monitoring/assessment (CPM/CPA) applications (Jelali, 2005). According to the author, these applications use controllers which reference some set water metrics or benchmarks relative to standard production rate, in order to ensure an optimal productivity in pulp and paper processes.

2.6 Manufacture of Basic Metals (SIC Division 24)

2.6.1 Overview of basic metal manufacture processes

As clearly defined by Homma (2010), basic metals are metals produced *"from ore, scrap and conversion of billet, slab etc., into primary metal products"*; they are in contrast with metals classified as precious or noble such as Gold and Silver. Basic metals are categorized into two major groups – the iron and non-iron-based metals, where the former consists of stainless, carbon and ferrochrome steel, while the later contains aluminium, brass, manganese, copper, tin and lead.

In metals production and transformation, different processes require varying intensities of water; from the extraction stage through the purification processes to the healing of metals, vast amount of water is required. Although, the greatest water use and consumption in this sector is attributed to the cooling process (EC, 2009).

In England and Wales, the manufacture of basic metals sub-sector is the third largest abstracted water user in the manufacturing sector and the largest in Wales alone, accounting for at least two-thirds of Welsh total water volume directly abstracted for consumptive uses in 2006.

As noted by Çağin and Yetiş (2011), basically, the iron and steel manufacturing industry is one of the oldest industrial sectors that uses water, in almost every step of the process chain, in large quantities. In practice, the presence of impurities such as carbon, sulphur, silica and phosphorus weakens the strength of the metals tremendously; steel which is a purified bye product of iron has a carbon concentration of 0.5% – 1.5%. Yet, removal of these impurities also requires discrete amounts of water. Table 2.13 provides water requirements for processing coke to Iron, then Iron to Steel. Succeeding sections of this study will detail the specific water use intensities of steel production processes.

Step		Process Water (L/kg product)
Cokemaking		0.45 - 3.41
Ironmaking		12.11 - 22.71
Steelmaking		
	Electric Arc Furnace	7.95
	Basic Oxygen Furnace	3.79 - 4.16
Refining and Casting		
	Vacuum Degassing	4.73 - 5.30
	Continuous Casting	13.63
Forming and Finishing		
	Hot Forming	5.68 - 24.23
	Cold Forming	Data not available
	Oxidizing Operations	1.25 - 6.44
	Reducing Operations	1.23 - 6.89
	Acid Pickling	Data not available

Table 2.13: process water requirements of Iron and steel manufacture

Adapted from: Ellis et al. (2001, p. 4)

The succeeding sections of this study will detail the specific water use intensities of steel production processes.

2.6.2 Specific Water Intensities (SWI) of steel manufacturing processes

In contemporary times, per unit water use in the steel industry is less than half of what was used 20 years ago (GLC 1996, cited in Ellis *et al.*, 2001); this is so because more recent plants are designed with enhanced water use efficiency and capabilities of greater water recycling. As asserted by Ellis *et al*., (2001), over 96 percent of the water used in steel manufacture is actually recycled within the production plant, and mostly, the used water is returned to the source even cleaner than it was before intake (AISI 2000, cited in Ellis *et al*. 2001).

Water use in the steel industry is mainly for cooling: equipment, intermediate steel shapes and furnaces; as a source of steam; wet scrubber fluid for air pollution control; and cleansing agent to remove scale from steel products (EPA, 2008). Normally, the equipment efficiency, steel type and shape being produced and the efficiency of the equipment all contribute to the level of water requirement in the steel manufacture (Ellis, *et al.*, 2001). But not all processes in steel manufacture require water. A detailed process outline of steel manufacture is given by the Environment Agency (2003) as follows:

- Coke manufacture: this is basically prepared from superior quality coal heated for 18 hours.
- Preparation of Ore and sintering: involves passing Ore beneath a sintering hood to produce an iron-rich material known as sinter.
- De-sulphuring: Usually achieved by injection of magnesium
- Basic oxygen introduction: At this stage, oxygen is forced across the molten iron to enable the oxidation and removal of unwanted gases and slag. The addition of Ferro-alloy then helps in making the required steel composition.
- Final specification: This involves stirring the molten iron with argon and trimming same to final specification, then degassing the vacuum to remove dissolved undesired gases.
- Casting: This stage involves casting the molten steel into slabs or forms or blooms, or teemed into ingots.
- Milling: The steel in slabs, ingots and blooms are rolled into finished products, while the billets are sold directly to customers (EA, 2003)

Assessing the complete steps of steelmaking, the water intensive processes were deduced in a recent study by Çağin and Yetiş (2011) and the specific make-up water consumption for each process was derived. The result of their study is revealed in table 2.14.

Process	Specific make-up water consumption ($m^3\ t^{-1}$ product)
Coke making	0.562
Sinter plants	0.138
Blast furnace	1.462
Basic oxygen furnace	1.487
Continuous casting	0.456
Hot rolling mills	0.935
Support processes	5.07
Total	10.12

Table 2.14: specific make-up water consumption for each steelmaking process

Adapted from: Çağin and Yetiş (2011)

2.7 UK Water-Energy Nexus

2.7.1 Overview of problems and prospects of the UK water-energy nexus

Water, Energy, Waste, Transportation, Information and Communication Technology (ICT), etc., all constitute the national infrastructure in UK (Watson and Rai, 2013). These infrastructure sectors contribute in distinct ways to the value chain of each other, giving rise to a complementary relationship which entails a form of support to ailing sectors. It also means that failure of a sector which is heavily relied upon by other sectors will induce a cascade of failures or poor productivity in the dependent sector(s). For instance, electricity failure will critically impact on water processes, while ICT failure will have severe effects on water and power sectors as these greatly rely on ICT (Buldyrev *et al.*, 2010). Accordingly, Watson and Rai (2013) have reasoned that a plan to improve drinking water quality or upgrade a wastewater infrastructure may in turn intensify energy input or GHG emissions. Thus, the need to explore the water-energy tie is intensified by the heavy reliance of other sectors on both water and energy.

Suffice it that, in recent times, there have been studies and reports integrating the old isolated issues of energy and water under the spectrum of planning, policy formulations, facility designs and operations. Although, research on the interdependencies of these resources only started proliferating in the past few decades, Gleick (1993) concedes that America long realised the need to assess the problems and prospects of this bond, and proactively structured policies and projects to ensure that potential phenomenal challenges to either of the regimes (water or energy) do not uncontrollably impact on the other.

Various universities have also initiated programs to research into predominant links between water and energy. Regarded as a crucial and unacknowledged linkage, the Australian National University recently launched a collaborative research programme called the Australia-United States Climate Energy and Water Nexus (AUSCEW), aimed at exploring the water-energy link relative to climate change, and identifying holistic policy recommendations that will help evade adverse impacts of resource insufficiency and favour mutually beneficial solutions (AUSCEW, 2012). More so, in the United States, Harvard University has advanced scientific research on the theme: *"Energy's growing need for water"*, targeted at deducing prevailing constraints to sustainable development which lie in the interconnections of individual sectors (SSP, 2013).

Water which is one of the most fundamental requirements of life, is both a human right and an economic good (UNESCO, 2003), while energy is critical to the provision of water. Whereas, water is important in energy production and energy plays a great role in water management, the interdependence of these two resources is known as *"water-energy nexus"* (Siddiqi and Anadon, 2011).

Several authors have claimed that relative to the significant research efforts in water and energy in isolation, the water-energy nexus remains under-explored globally (Gleick, 1993; Webber, 2008 and Siddiqi & Anadon, 2011). Only a few peer-reviewed literature highlight energy intensities of water abstraction, purification and distribution in UK, as most researches on the water-energy relationship focus on water use in electricity production (Watson & Rai, 2013).

It is therefore imperative to bridge this gap in knowledge in order to address the imminent challenges of water and energy insecurity in the wake of the ever-increasing demand for these resources. Thus, to achieve this, a comprehensive link between energy and water will be developed in the succeeding part of this study, so as to clearly understand where barriers exist in the integration strategy and identify best practice approaches that could be applied to optimally harness this relationship in UK.

2.7.2 Resource availability and sustainability

In order to undertake processes that heavily rely on water or energy, there is need to establish the sustainability credential of the resource to be used. Numerous events in different parts of the world serve to underscore the energy and water interdependence in terms of resource availability and sustainability.

A resource may be available but not sustainable; this automatically means that processes reliant on such resource will in turn be unsustainable. For instance, whereas, coal-to-liquid (CTL) plants are extensively water intensive processes, according to reports, china suspended its plans to construct a CTL plant given its potential long term effect of drought and negative impacts on the quality and availability of the already over-stressed Chinese water resource (Xinhua News, 2006).

It is pertinent to state that in 2005, about 49% of all water withdrawals or 41% of all freshwater withdrawals were used by the US thermoelectric power plants alone (Kenny *et al*., 2005). Accordingly, following the report that Lake Mead which is the largest reservoir in US is currently 100 feet lower than its historic level, it has in turn been predicted that a further reduction to the extent of 50 feet will cause the Hoover Dam hydroelectric turbines to produce very little or even no power; thus, placing Las Vegas in a state of critical resource reduction and potential need for cross-border trade (Webber, 2008).

It will also be recalled that in July 2009, France had to import power from UK. This followed the cooling water temperature remarkably exceeding the permitted discharge temperature of 24°C due to the prolonged heat wave at the nuclear plant which eventually led to the shutdown of 20GW of the total 63GW nuclear power capacity of France (Pagnamenta, 2009). Yet, earlier in summer 2003, the same effect of intense heat wave compelled French regulators to grant an official approval which allowed nuclear plants to discharge their cooling water at about 40°C (Siddiqi and Anadon, 2011).

These coevolving relationships have prompted Governments in Countries like US, China, Canada, Australia and Spain to initiate formal strategies to detail this water-energy nexus. The ultimate goal being to develop integrated policies and more robust technologies that will help secure the availability of these resources in the future.

2.7.3 UK water use in the energy sector

The study on Water Use by Gleick (1993) has been one of the pioneer research efforts that provided an insight into the quantities of water used for various power generation processes, while a detailed set of water use benchmarks for comparing performance in thermoelectric power generation was first published by Dziegielewski *et al.* (2006). Accordingly, the U.S. Department of Energy (2006) came up with comprehensive estimates of water use by major power generation types which incorporated contemporary technologies and renewable sources of energy.

Sampling part of UK, abstraction rates for various purposes in 2008 alone, are revealed in figure 2.22. In England and Wales, a high percentage of water licensed for abstraction is actually not abstracted. According to the UK Environment Agency (2011), a total of 34,500 Ml/d of water was abstracted out of the 75,000 Ml/d of water licensed for abstraction; that is, 46.01% was actually abstracted. Water abstracted for public water supply totalled 46.6% (almost half of the actual water abstracted) although, more than 70% was returned as treated effluent (EA, 2011).

Being a projected quantity, the licensed abstraction is estimated to take care of contingencies or variations in outcome. Thus, it is considered that water used for electricity generation varies according to annual run-offs and could peak in very wet years like 2012. Although it is noted that water abstracted for electricity was 35.35% in England and Wales, but in Wales alone, over 80% of abstracted water is used for electricity generation, while about 15% is withdrawn for public water supply (EA, 2011).

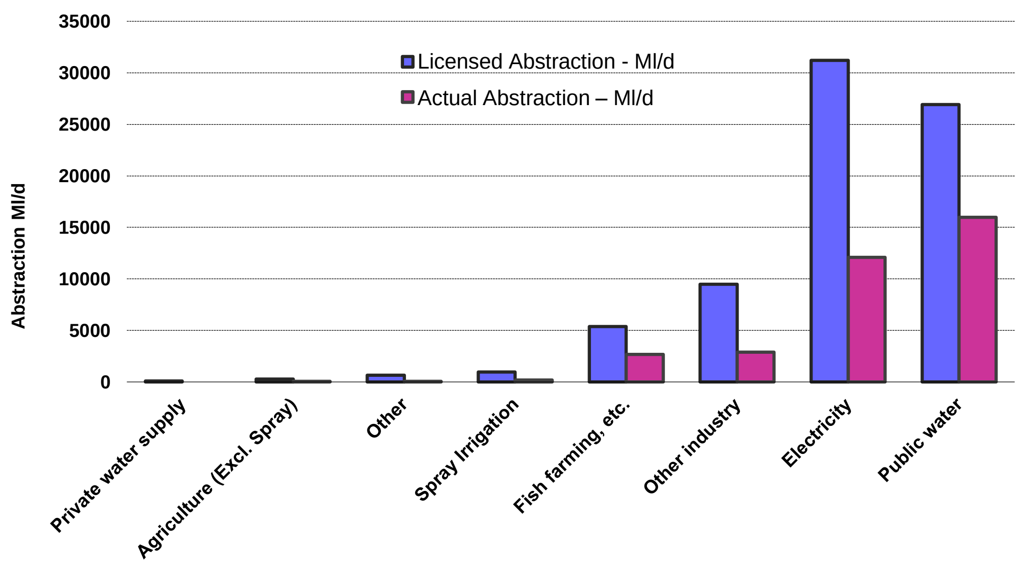


Figure 2.22: Water abstraction by various sectors Didcot

Source: Environment Agency (2011)

In the field of energy, the research conducted by Schoonbaert (2012) reveals that the quantity of water consumed in power generation is mainly a function of the generation type, fuel type, cooling technology used for the thermoelectric power generation, or the carbon capture and storage facility (CSF) used in the fossil fuel power plants. A summary of water use by various technologies is depicted in Table 2.15. The table provides an estimate of water consumption rates for different power generation technologies.

Fuel Type	Cooling	Technology	Withdrawal (Litre / MWh)			Consumption (Litre / MWh)		
			Median	Min	Max	Median	Min	Max
Nuclear	Tower	Generic	5,005	3,637	11,820	3,055	2,641	3,841
	Once-through	Generic	201,619	113,652	272,765	1,223	455	1,818
	Pond	Generic	32,050	2,273	59,099	2,773	2,546	3,273
Natural Gas	Tower	Combined Cycle	1,150	682	1,287	900	591	1,364
		Steam	5,469	4,319	6,637	3,755	3,010	5,319
		Combined Cycle with CCS	2,255	2,214	2,300	1,718	1,718	1,718
	Once-through	Combined Cycle	51,735	34,096	90,922	455	91	455
		Steam	159,113	45,461	272,765	1,091	432	1,323
	Pond	Combined Cycle	159,113	45,461	272,765	1,091	1,091	1,091
	Dry	Combined Cycle	27,049	27,049	27,049	9	0	18
	Inlet	Steam	9	0	18	1,546	364	2,728
Coal	Tower	Generic	1,932	455	3,410	3,123	2,182	5,001
		Subcritical	4,569	2,273	5,455	2,141	1,791	3,019
		Supercritical	2,414	2,105	3,082	2,241	2,082	2,700
		IGCC	2,769	2,646	3,041	1,691	1,446	1,996
		Subcritical with CCS	1,773	1,628	2,750	4,282	4,282	4,282
		Supercritical with CCS	5,805	5,564	6,042	3,846	3,846	3,846
		IGCC with CCS	5,105	4,992	5,219	2,455	2,373	2,537
	Once-through	Generic	2,664	2,178	3,082	1,137	455	1,441
		Subcritical	165,250	90,922	227,305	514	323	627
		Supercritical	123,144	122,954	123,258	468	291	564
	Pond	Generic	102,696	102,519	102,792	2,478	1,364	3,182
		Subcritical	55,576	1,364	109,106	3,541	3,350	3,655
		Supercritical	81,439	81,189	81,498	191	18	291
Biopower	Tower	Steam	68,400	68,173	68,450	2,514	2,182	4,387
	Once-through	Steam	3,991	2,273	6,637	1,068	1,068	1,068
	Pond	Steam	159,113	90,922	227,305	1,364	1,364	2,182
	Dry	Biogas	-	-	-	159	159	159
Hydropower	N/A	Aggregated in-stream & reservoir	2,046	1,364	2,728	-	-	-

Table 2.15: Water withdrawal and consumption rates for major power generation sources

Macnick et al. (2011)

2.7.4 Energy use in water sector

Several researchers have variously highlighted the role of energy in water management. Water abstraction, treatment, desalination and distribution are very energy-intensive processes and these energy implications of water processes are often predicated on the original status (fresh or sea water) and location of the resource.

Concise uses of energy in water processes have been summarised by Watson and Rai (2013) as follows:

- Water abstraction and conveyance: Pumping from source (Ground or Surface) and transfer to reservoir or treatment plant.
- Treatment or purification and distribution of water: Advanced processes such as UV and Ozone applications require greater energy application, while distribution requires lots of energy for pumping.
- Heating, cooling and use of water in facilities for domestic, commercial and industrial purposes; these require varying amounts of energy.
- Wastewater treatments; often requiring highly energy intensive processes to collect, physically segregate, chemically treat, discharge treated effluent and landfill sludge.

2.7.5 Problems and Prospects of the Energy-Water Nexus in UK

According to DETR (1998, p.1), *"Pumping costs UK industry over £1,400 million in electricity each year, mostly for pumping water and estimates suggest that over 20% of this figure could be saved"*. Also, in the food manufacturing sector alone, the water expenditure is approximately £300 million annually, while energy is £800 million and estimates indicate that a 20% reduction in water use could save the food industry £60 million a year (FISS, 2007).

Worthy of note is that the water-energy links vary with the availability and nature of the water resource which is often a function of climate variability. With the Atlantic Ocean bordering Scotland, 70% of the surface area and 90% volume of the water in the entire UK are providentially located in Scotland (Scottish Natural Heritage, 2001). This condition underscores the great hydro potentials of Scotland and has led to the formulation of frameworks and design of strategies to harness the water resource, including its tides and waterways. Typical examples are the Scottish Renewables Obligations (SRO) which is Scottish Government's main means of increasing electricity generation from renewable sources – legislated for in the Renewals Obligation (Scottish) Order 2006 (SI) 2006 No. 1004 (The Scottish Government, 2013); and the recent Scottish Hydro Agenda aimed at harnessing Scotland's vast water resource, advancing water technologies and delivering economic gains (Scottish Government, 2012).

The need to align this water-energy scrutiny becomes even more intensified following the prediction that *"by 2030, hydropower will become the world's dominant renewable energy source, providing more than twice the amount of its nearest rival, on shore wind power"* (Waughray 2011, p.10). Accordingly, *"UK's energy demand is forecast to increase by 36% between 2011 and 2030"* (BP, 2013, p.4), with 15% projected to be supplied from the renewable sources by 2020 (DECC 2011, p.5). But the UK with 2650m^3/year of water per person (Kaczmarek, 1995) is already classified as a country with *"low"* water availability (Holt *et al*., 2000). Thus, where UK is faced with any spike in water demand, potential aftermaths may include: cross-border trade or trade-offs, or desalination of sea water.

2.7.6 Water implications of thermal plant electricity generation

Thermal power plants use great amounts of water for cooling. New technologies such as the combined cycle gas turbine power plants are acclaimed low water intake technologies, yet they end up having higher net water consumption. Also Biofuel use has been considered as a strategy to reduce carbon dioxide emissions and oil import; however biofuel is the most water-intensive source of fuel, and its use in large scale means increasing water consumption in energy production (Mielke *et al.,* 2010).

Accordingly, thermal power plants are responsible for roughly 80% of global electricity production and account for 49% of total freshwater withdrawals in USA and 43% in Europe (UN WWAP, 2014). In the UK, of the more than 75% freshwater withdrawal for electricity generation, 5% is actually used for thermal generation; whereas, 95% is used for hydropower (EA, 2013). Yet, power stations in the UK are currently closed down following the implementation of stricter regulations on emissions from fossil power by existing power stations. For instance Didcot A, a dual fired power station which used tower cooling when operational was closed down in March 2013 (EA, 2013); and the Environment Agency (2013) has predicted that more plants are set to be closed by 2016 and possibly others by 2023.

Suffice it that, hydropower currently contributes 2.5% of the UK's total electricity generated; 1% of which is generated in England and Wales (DECC, 2012). This condition does not favour the UK strategy of 15% energy supply from renewable sources by 2020.

2.7.7 Thermal power cooling technologies

In thermal power generation three major cooling technologies (best available technology) are generally used, these range *"from once through (best thermal efficiency), wet tower cooling (mid ranking thermal efficiency) to air cooling (lowest thermal efficiency)"* (EA 2013, p. 1, 2). Of the two that are mainly used in the UK - the direct and tower Cooling technologies, the once through (direct) cooling is the most common cooling technique presently used. These two major cooling technologies are detailed in figure 2.23.

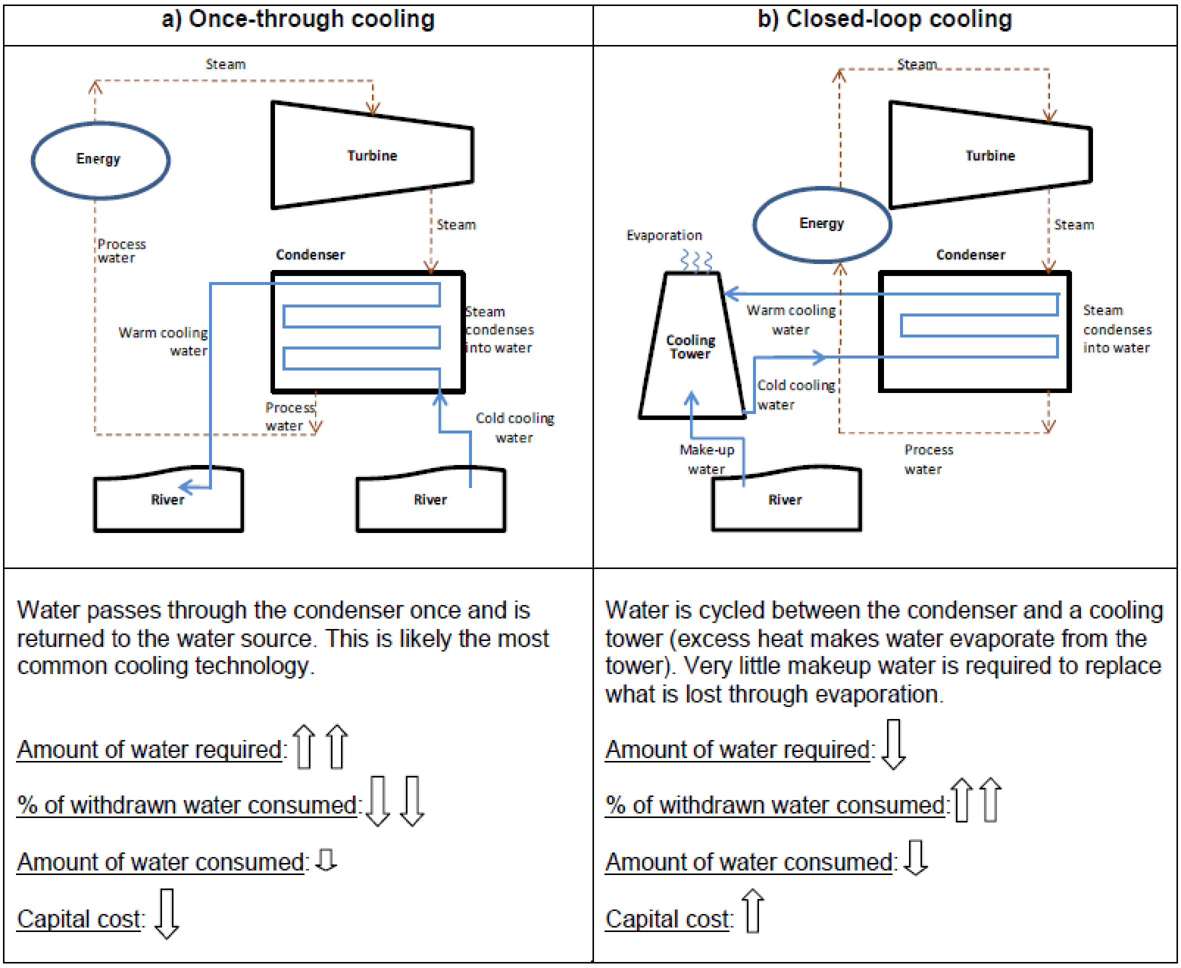


Figure 2.23: Cooling technologies used in thermoelectric power generation - Once through and closed loop

Source: Kohli and Frenken (2011).

2.7.8 Water withdrawal and consumption misconceptions in electricity generation

At the mention of large withdrawals, one thing often quickly comes to mind: high consumptions. Once-through cooling requires very large volume of water which is actually only passed through the condenser as cooling water and eventually returned; thus, available to the downstream users.

However, this process still leads to water evaporation, as the water temperature ends up increasing by 10-15°C (Kohli and Frenken, 2011). The 10-15°C temperature range may again be considered relatively small, but given the volume of water passed through in each cycle, a significant amount of water ends up being evaporated, hence consumed.

This is different in the closed loop where cooling water is regularly topped up only to be eventually evaporated, thus consumed and not available to downstream users. Table 2.16 reveals how water is consumed in the thermal plant using different cooling technologies and fuels. It shows how 3000 litres/MWhr can be taken up and completely consumed as in the case of nuclear steam when considering the closed loop cooling.

On the other hand, hydroelectric water withdrawal being an in-stream water use is often not seen as a water consuming electricity source. Yet, from estimates, hydropower evaporates approximately 17m^3 of water per Mega Watt Hours of energy generated (ADB 2013, p.14). This again is water consumed.

Plant and Cooling System Type Water	**Withdrawal (liters/MWh)**	**Consumption (liters/MWh)**
Fossil fuel/biomass/waste | once-through cooling	76 000 - 190 000	1 000
Fossil fuel/biomass/waste | closed-loop cooling	2 000 - 2 300	2 000
Nuclear steam | once-through cooling	95 000 - 230 000	1 500
Nuclear steam | closed-loop cooling	3 000 - 4 000	3 000

Table 2.16: Approximate water withdrawals and consumptions, not accounting for ambient temperature or plant efficiency

Rounded and adapted from EPRI (2002, cited in Kohli and Frenken, 2011)

2.8 Quantifying the UK Water-Energy Nexus

2.8.1 Water Use in Energy Processes

Figure 2.24 provides estimates of total licensed abstractions in England and Wales. It shows that for electricity supply, after a 2,525 Million cubic meters increase in water abstraction between 2000 and 2001, the abstraction volume had fallen steadily from 29,571 Million cubic meters in 2001 to 27,471 Million cubic meters in 2006; while from 2007 – 2012, water abstraction volume increased by 7,699 Million cubic meters for electricity supply.

Water abstraction for public water supply had been fairly steady with difference between the highest (in 2005) and lowest (in 2009) abstraction totalling 573 Million cubic meters. Water used in fish farming has drop from 1,723 Million cubic meters in 2000 to 974 Million cubic meters in 2012, while industrial water use had relatively reduced after it peaked by 2418 Million cubic meters in 2003.

On the average, 76.03% of the total water abstraction was used for electricity supply, 15.51% for public water supply, 5.20% by industry, 3.15% for fish farming, while *"other"* water uses constituted 0.11%. Thus, water abstraction by the electricity sector of England and Wales was the largest, and has continued to grow remarkably. Whereas, more rainfall leads to reduction in water abstraction for irrigation and fishing, the mark increase in water use for electricity supply between 2011 and 2012 can be attributed basically to 2012 been the second wettest year in UK since 1910, with rainfall average of 1,330.7mm preceding the 1172.5mm of the previous year – 2011 (Met Office, 2014). Reduction in water use in the industrial sector can be linked with the application of more efficient water and wastewater facilities in recent times.

According to the UN, circa 75% of all industrial water withdrawals are used for energy production. As shown in figure 2.24, in England and Wales alone, the licensed water abstractions exceed this percentage.

Figure 2.24: Licensed water abstractions in the England and Wales

Data Source: Environment Agency (2013)

2.8.2 Energy use in water processes

A clear summary of energy intensities of water and waste water treatments has been presented Figure 2.25. Critically analysing the trend, it is established that except in 2002/03 when energy used in treating 1ML of water slightly rose by 18kWh above that used for treating 1ML of sewage, wastewater treatment energy intensities have remained higher over the other years. Water treatment energy intensities have been on the decline from 2003/04 to 2006/07. It took 559 KWh of energy to treat one Mega litre (1ML) of water and 756 kWh of energy to treat 1ML of sewage in the year 2006/07. Relative to the previous year (2005/06), energy used in treating wastewater increased by 122kWh/ML while energy used in treating water reduced by 27kWh/ML following an earlier drop between 2004/05 and 2005/06 by 77kWh/ML. Sludge aeration has been considered the most energy intensive process in wastewater treatment (Caffoor, 2008).

A major reason for the increasing energy usage in wastewater treatment is the implementation of the stringent WFD quality requirements of *"good ecological status"* for UK waters by 2015. The directive according to Watson and Rai (2013) is predicted to cause further increase in the energy intensities of water and wastewater treatment to almost 100%.

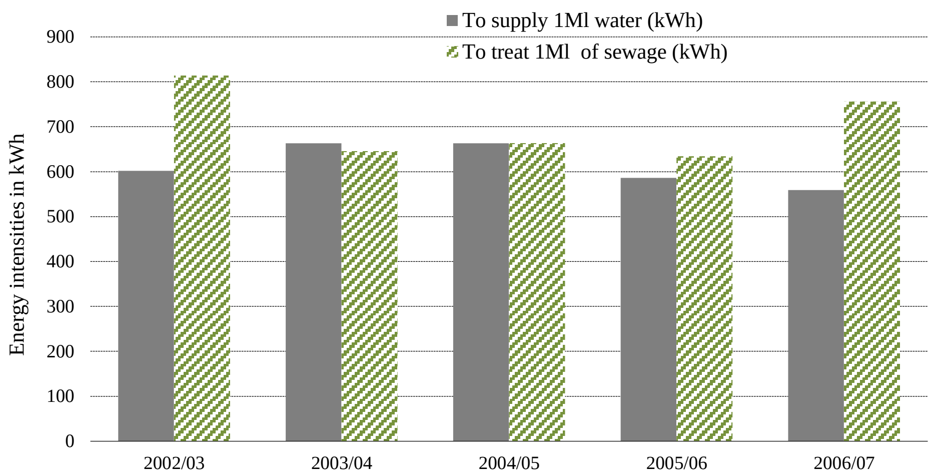


Figure 2.25: Energy intensities of treating 1ML of Water and Sewage

Data source: Water UK (2007)

Figure 2.26 indicates electricity generated in UK from major fuel types. Between 1999 and 2011, natural gas constituted the dominant fuel in relative terms, representing 40.04% of all UK energy generation; while solid fuel produced a total of 35.11% of the UK energy. Although the decline in coal usage between 2006 and 2011 may be attributed to the high prices of coal especially relative to gas; however, in 2012 solid fuel accounted for the main electricity generation, with an increase by 53.93TWh above that generated from gas.

From this account, it is inferred that the UK fossil capacity is still high, representing 75.92% of the total energy generation, while, electricity from the nuclear source stood at 22.94%. Nuclear energy has remained less than the 99.49TWh generated in 1998, although it increased by 8.27TWh between 2010 and 2012.

The hydro energy constitutes only 1.14% of the energy generation, while the share of oil has remained insignificant. In a nutshell, the chart shows that UK energy sector is heavily reliant on the Gas, Coal and Nuclear fuel sources, and explores less of the Oil and Hydro sources of energy.

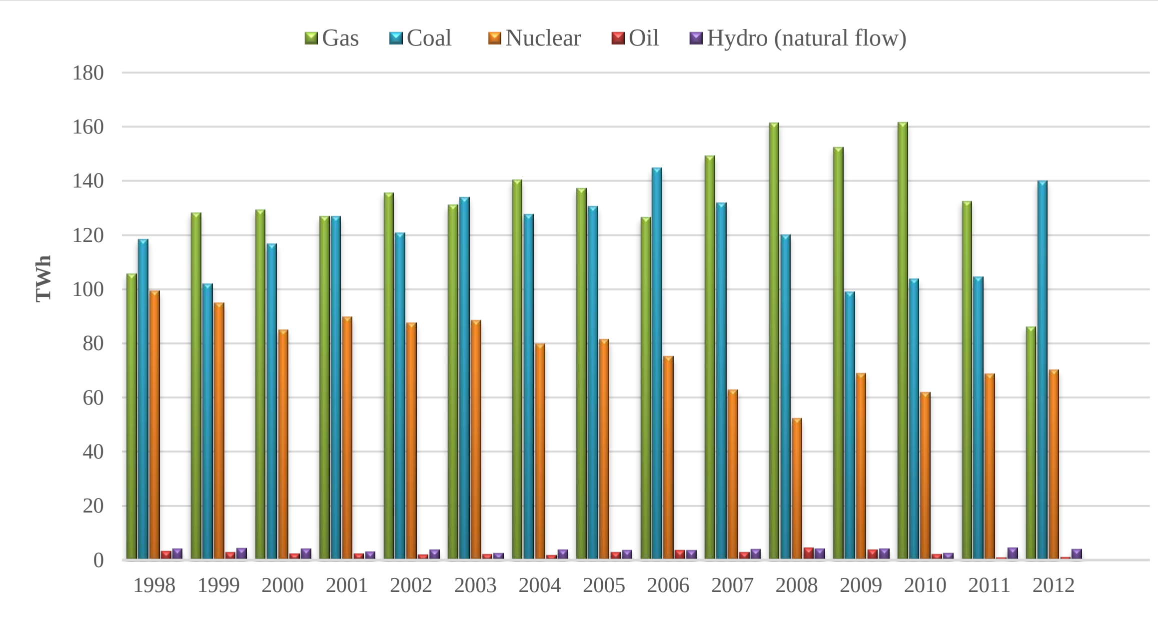


Figure 2.26: Total electricity generated in UK from major fuel types

Data source: DECC (2014b)

The sharp increases and declines in UK Hydro energy generation from 1998 to 2012 as shown in figure 2.27, is mainly attributed to external factors such as annual rainfall averages and seasonal variations like heavy rains in winter. From figure 2.27, it is deduced that 69.95% increase in electricity generation happened between 2010 and 2011, then a 9.24% decrease in 2012 and a further decline by about 13.45% (0.54 TWh) in 2013. The high energy generation between 2011 and 2013 follows the heavy rain in UK during these periods especially in 2012.

Hydropower with a conversion efficiency of above 85% remains a predictable and reliable source of energy in the UK. The hydro resources of the UK can still be further harnessed through extra development of small and micro-scale hydro schemes from municipal to national level.

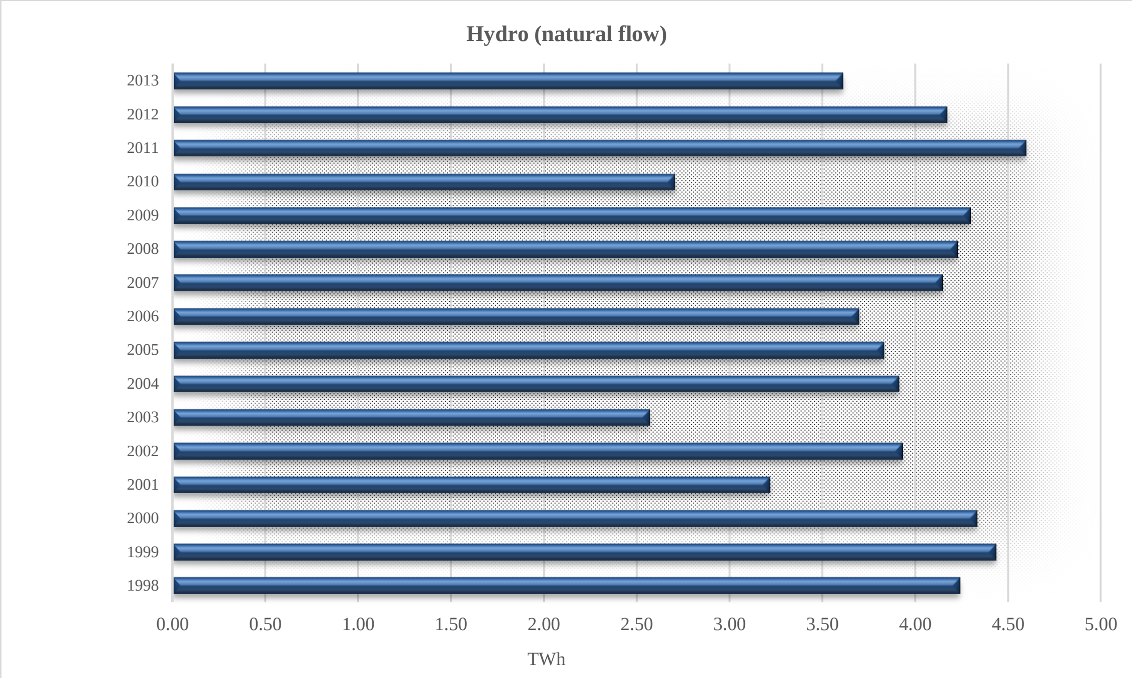


Figure 2.27: Total hydro electricity generated in UK (1998-2013)

Data source: DECC (2014b)

Figure 2.28 reveals how UK regions generate their hydroelectricity. It can be seen that the energy generated by Scotland peaked in 2005 totalling 6756GWh; then it sharply dropped in 2010. The decline is traced to the average rainfall in UK averaging 952mm in 2010 and increasing to 1331mm in 2012 (Met Office, 2014); this condition is actually consistent with the impact of annual run-off on hydro energy generation.

In Wales, there is a relatively consistent trend in the energy generated. The generation gradually kept increasing from 2004 to 2008, then it started declining, but has risen again from 2011. The chart therefore shows that Scotland has the highest and growing hydro potential while Northern Ireland has the least contribution to hydro energy generation. This supports the claim that England and Wales has hydro potentials in the range of 146 to 248 MW (British Hydro Association, 2010) while Scotland's hydro potential is in the region of 2,593 MW (BHA, 2008).

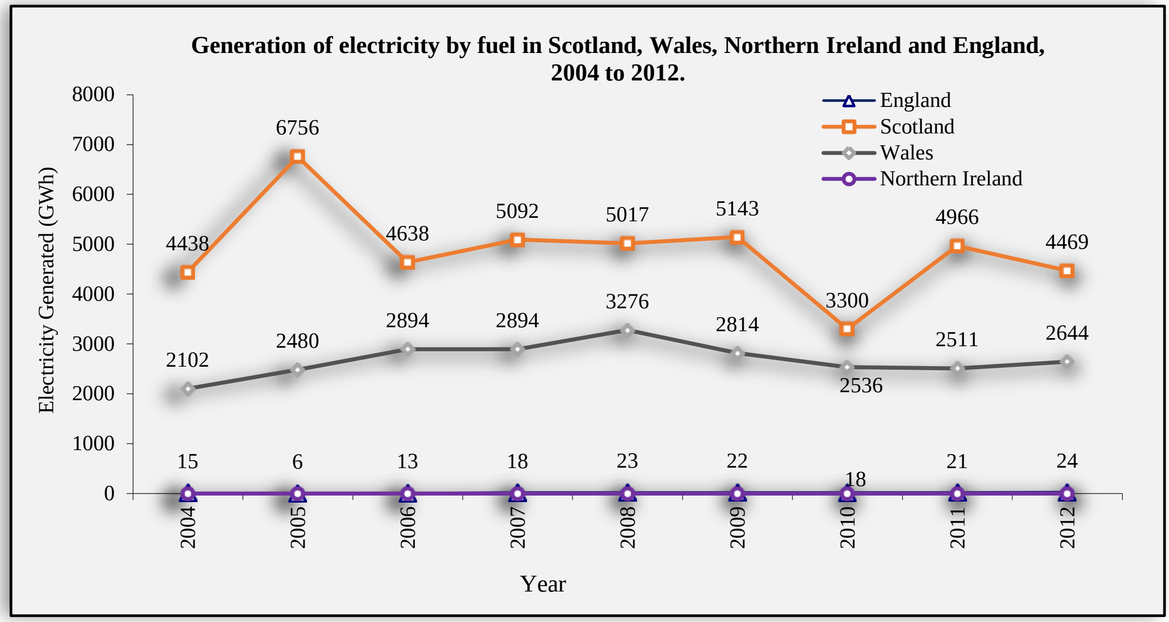


Figure 2.28: Electricity generation and supply from Hydro flow for Scotland, Wales, Northern Ireland and England, 2004 to 2012

Data source: DECC (2013a)

The report by UK Water (2010) reveals that renewable energy generated by water and wastewater companies in the UK totalled 665 GWh in 09/10 relative to the 742 GWh generated in 08/09. This been a downward trend, strongly challenges the goal of generating 15% of UK's energy from renewable sources in 2020. Although, UK has put in place renewable financial incentives through the Renewables Obligation (RO) Scheme which provides renewable electricity generators with financial support more than what they receive from selling same to the wholesale market (The Scottish Government, 2013).

At the moment, UK hydro receives financial support from Government through the RO. It is reckoned that the RO will help reduce the investment cost and boost the overall competitiveness of the hydro technology relative to other established sources of electricity (HM Government, 2009).

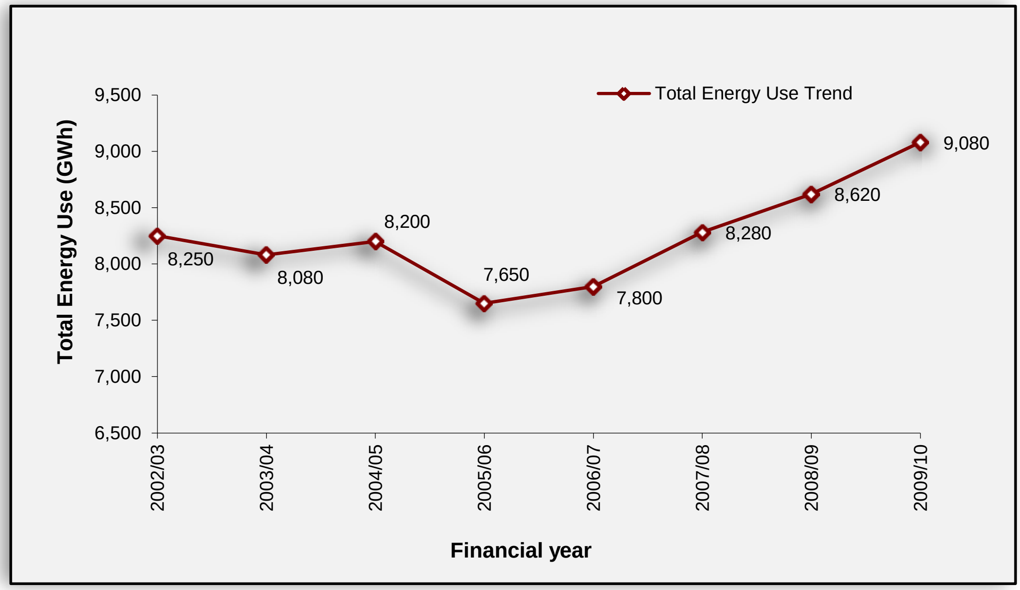


Figure 2.29: Total energy use by UK water sector

Data source: UK Water (2010)

In total, energy use by the UK water sector increased by 4% between 2008/09 (8160GWh) and 2009/10 (9012GWh) with the trend presenting high possibility of future growth in energy intensities as revealed in figure 2.29. This energy use is the energy from electricity and gas for water and wastewater pumping and treatment (operational purposes), and for administrative functions, excluding transport (UK water, 2010).

2.8.3 Water-energy interdependence

Whereas thermoelectric and nuclear plants take up as much as 90% of fresh water abstracted for energy purposes (mainly cooling), and air cooling is relatively not an efficient cooling strategy, the use of a hybrid system (encompassing water and air) will help reduce the water taken up by the energy sector.

There is need for a standard accounting system by both the energy and water undertakings. This will serve as a gauge for measuring the consumption rates of these resources and means of identifying possible best practices. A department should be created to oversee the implementation of this water-energy integration strategy; this unit should work closely with Ofwat and Ofgem (the UK water and energy regulators respectively) to identify possible problems and prospects of any planning or provision of either the water or energy resources. Thus, an integrated approach to assessing both resources will help eliminate any wasteful or unnecessary duplication of ideas and reduce conflicts of interest that are often associated with isolated strategies.

2.9 Deduced best practice resource saving measures for industrial processes

In the process benchmarking section of the *i*-Water Benchmarking Tool (figure 5.14: Qualitative assessment form), four major best practice water savings measures have been sub-detailed into 40 points. The four key subjects of the water savings measures include: Operational services; Maintenance, Government Policies; Staff education and awareness. This section condensed the findings of detailed researches into strategies of optimal industrial water use and savings. This is developed as an interactive platform to aid ease of engagement and drive behavioural changes in water use. However, in addition to the details revealed in the qualitative assessment form, below are other water conservation methods that are applicable to the industrial sector.

2.9.1 Focusing on areas of highest industrial water use

The industrial arena is very vast and any effective effort towards reducing the sector's water use will require an explicit identification of processes with very high water use. This is important because each industrial subsector's water demand depends on the subsector's core processes. Water demand in the industrial sector is chiefly alienated into three*:* for cooling, heating and as process water - with a shifting emphasis for each subsector (Ellis *et al.*, 2001). Figure 2.30 gives a comprehensive illustrative overview of how water is typically used in various industrial sectors on a national scale.

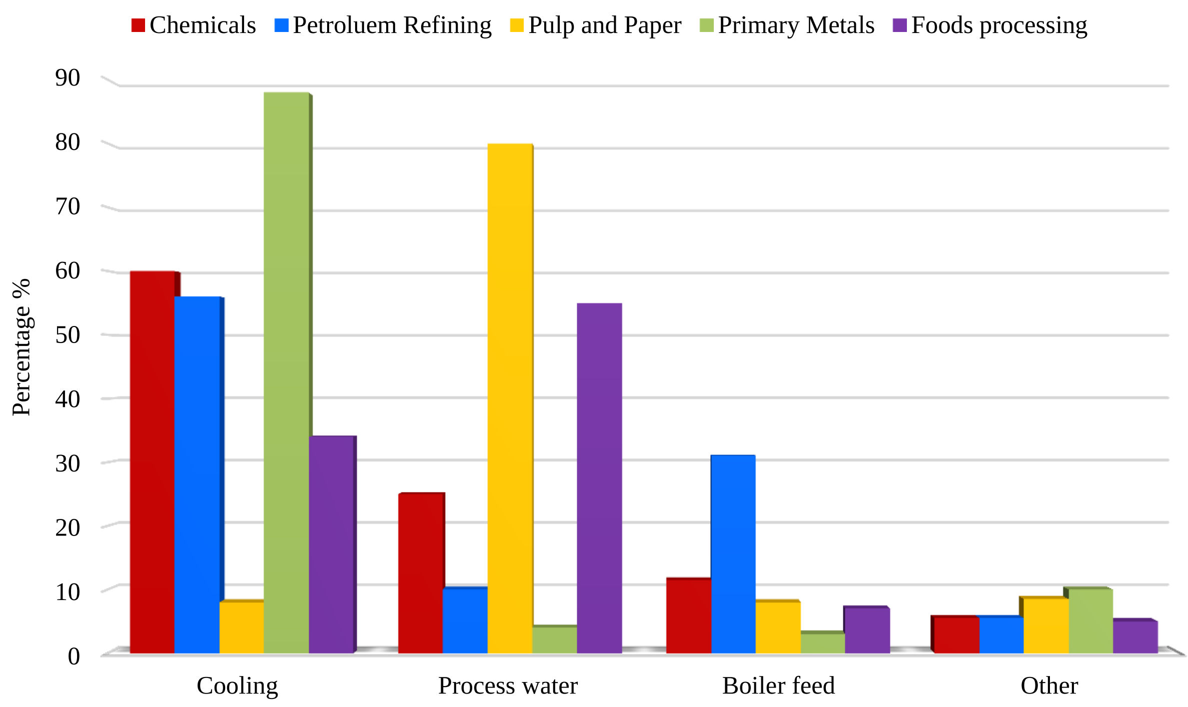


Figure 2.30: Water use types in various industrial subsectors

Source: Bowman (1998, cited in Ellis et al., 2001)

The figure above provides a reasonable indication of specific processes that use the largest volumes of water in industrial subsectors. From the diagram, it can be easily deduced that 80% of water used in pulp and paper is process water, and that primary metals use as much as 88.5% water for cooling purposes; whereas, process water constitutes over 55% of overall water use in food processes. Hence, any water conservation initiative should be focused on the water intensive processes for discrete subsectors.

2.9.2 Industrial washing and rinsing using the counter current approach

With sufficient number of tanks and an accurate flow rate, counter-current rinsing systems use substantially less water, while also being as effective as single-flow systems. This system helps conserve water used for washing and rinsing purposes. Figure 2.31 reveals a typical example of a counter current system.

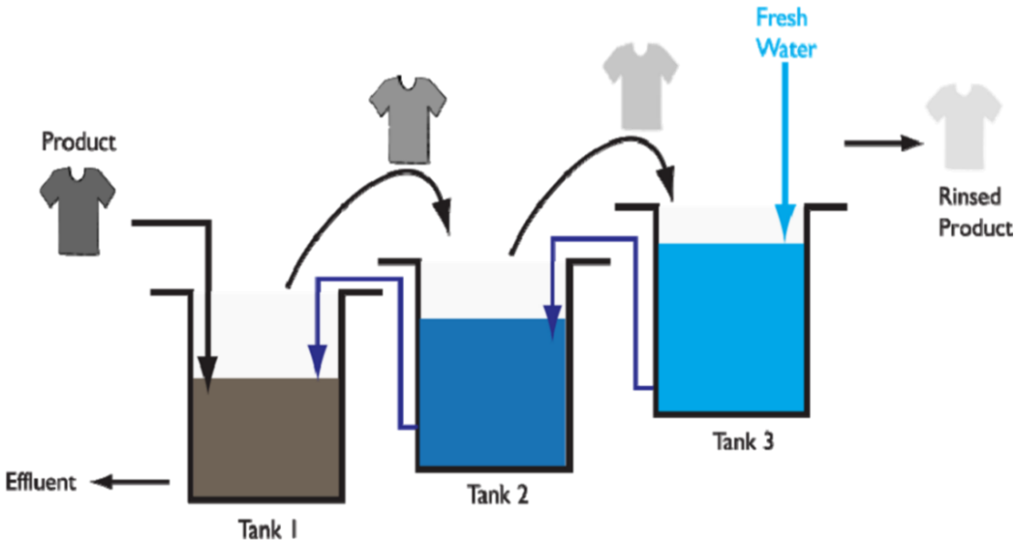


Figure 2.31: Counter current method of industrial washing and rinsing

Source: Arab Forum for Environment and Development (2010)

2.9.3 Water Reuse between businesses in industrial symbiosis

Industrial symbiosis involves sharing by-products among industrial sectors in order to optimise resource usage through partnership (SSWM, 2013, p.22).

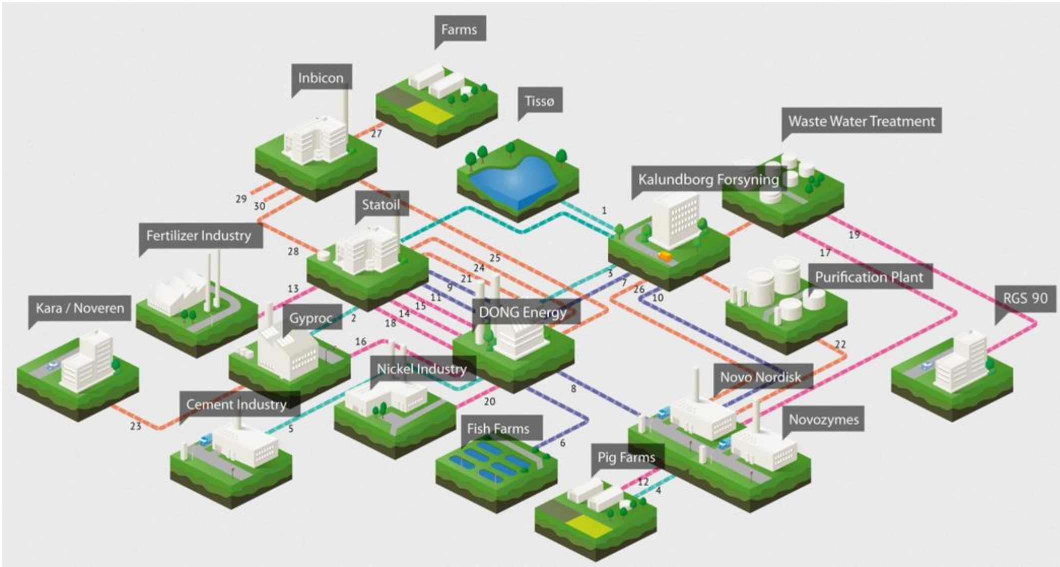


Figure 2.32: Kalundborg industrial symbiosis

Source: Kalundborg (2010)

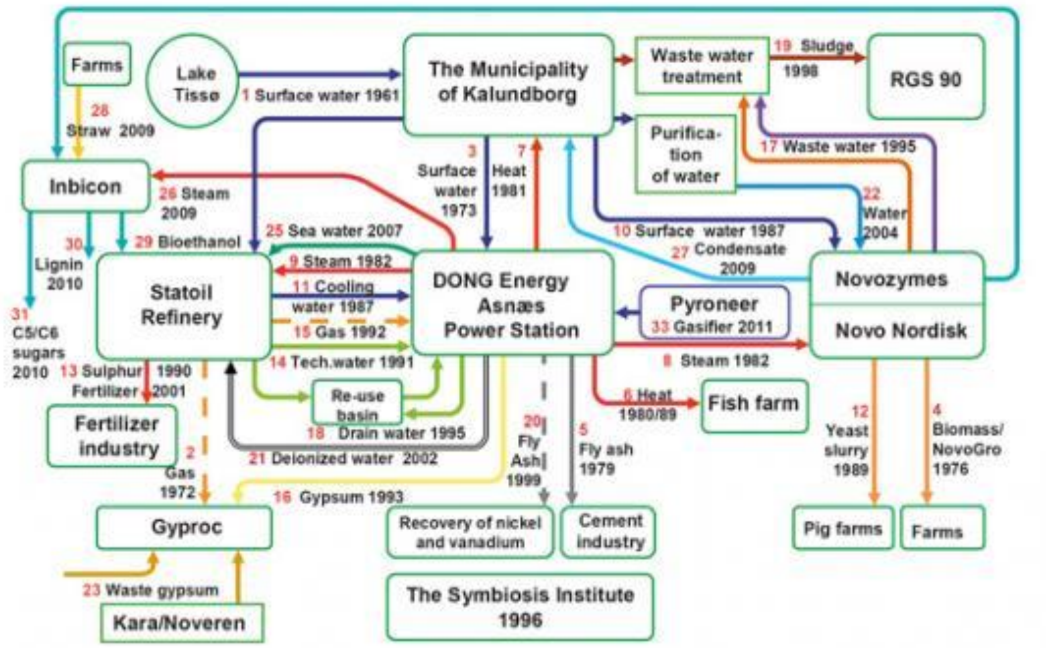


Figure 2.33: Working layout of Kalundborg Industrial symbiosis

Source: Kalundborg (2010)

As seen in figures 2.32 and 2.33, water (non-potable or used) is collected from Statoil and used in DONG Energy Asnaes Power Station for cooling. This implies that used water can be treated in the wastewater treatment plant and supplied to industrial companies based on the quality required. Instead of releasing reject steam into the atmosphere, it can be transferred to another company for use. This inter – company sharing of products and services symbiotically will help close the water use loop and reduce the cost of abstraction or treating water to drinking standard.

2.9.4 Wastewater recycle in industry

Step 1 **Water Use**	Mind what you mix in your water in order to minimise treatment effort.
Step 2 **Treatment**	• Possible treatment options for water reuse include: waste stabilisation ponds, aerated ponds, trickling filters, vertical flow constructed wetland, hybrid constructed wetland, free-surface constructed wetland and horizontal flow constructed wetland. • Treatment options where Biogas can be produced: Anaerobic digestion, e.g. UASB reactors, biogas settlers. • Advanced (more high-tech options): Activated sludge, MBRS, advanced oxidation processes, ozonation, activated carbon, reverse osmosis
Step 3 **Reuse**	Different water uses require different water qualities: Only reuse water for the purpose it was treated for!

Table 2.17: Industrial wastewater recycle

Bruni (2013, p.25)

Table 2.17 provides a detailed summary of industrial water recycling steps; from water use, through treatment of the wastewater to the reuse of the treated water for specific purposes. It can be deduced from the table that an effective water reuse begins with being conscious of what goes into the water in order to reduce the eventual treatment effort; then choosing the appropriate treatment method based on the anticipated quality of treated water; and lastly, ensuring that treated water is used only for the purpose it was treated. Further, in order to minimise overall water demand and volume of sewage treated at the wastewater treatment plants, water harvesting and reuse should be highly promoted

Chapter Three

3.0 Introduction

Providing a clear insight into the concept of performance assessment using benchmarking, this chapter explores various benchmarking application strategies, and details this to the water resource. Further, narrowing its global use to the UK water utility, a critical appraisal of cognate literature on water use performance measurement using benchmarking as a sustainability tool is captured in this section. Thus, the aim of this chapter is to investigate into the emergence, development, application and importance of benchmarks and benchmarking. It is construed that this will help explain how to source benchmarks where they are potentially available and how to create new ones where they are not available, inaccessible or not applicable to the task under consideration.

3.1 Global Benchmarking Strategies

3.1.1 Historical antecedents of benchmarking globally

As noted by CIPFA (1996, p.6) and Kelessidis (2000, p.2), *"benchmarking was pioneered by the Xerox Corporation"* in 1979 as a part response to the global *"competition in the photocopier market"* and became widely used in the US corporations in the 80's as means of competing favourably in the global market which was then prone to deregulations. Consequently, Rank Xerox's application of process benchmarking as highlighted by Camp (1989) and Spendolini (1992, cited in Jackson 2001), heralded the popularity of the benchmarking concept and adoption of benchmarking by different sectors of industries, organisations and businesses as a performance assessment method and Total Quality Management (TQM) tool. Accordingly, Kelessidis (2000) acknowledged that Xerox benchmarks approximately 240 performance elements in contemporary times, against the relatively limited elements they benchmarked years ago.

The European Foundation for Quality Management (EFQM) comprising of over 800 multinational and national companies is an organisation founded in 1988 to provide key strategic framework for promoting Total Quality Management and achieving global competitive advantage in business processes; while the Benchmarking Co-ordination Office (BCO) instituted in 1997 by the European Commission which is presently managed by the Irish Productivity Centre, provides robust benchmarking resource database and promotes benchmarking as a tool for improving market competitiveness and standard of living in Europe (Kelessidis, 2000).

Suffice it that the UK Quality Award of 1994 which followed the European Quality Award of 1992 has been noted to have heralded the prominence of benchmarking in the UK (Simpson and Kondouli, 2000). Currently in UK, the Confederation of British Industries (CBI) provides manufacturing databases for on-line assessment of practices and performance of the manufacturing companies (Kelessidis, 2000). It is also important to highlight that benchmarking of UK water utilities has got a legal backing as it is expressly legislated for in section 34(3) of the Water Act, 1991 which directs: *"the number of water enterprises which are under independent control … to make comparisons between different such water enterprises"* (Dassler *et al.*, 2006).

3.1.2 Overview of benchmarking efforts in the water sector

Numerous countries now conduct benchmarking on their water utilities for different purposes. As conceded by Larsson *et al.* (2002), Australia developed the *"syndicate benchmarking"* to help councils understand how best to apply benchmarking to their water processes, and America Water Works Association conducted benchmarking on Philadelphia water with the aim of gaining knowledge on how to apply the process benchmarking for optimal performance improvement. Countries like Canada, Netherlands, Mexico, Hong Kong, Italy and Poland have conducted benchmarking on their water processes with varying goals such as improvement on water and service quality, transparency and efficiency boost up, and enhancement of overall competitiveness of their industrial water users. In the UK, OFWAT examined levels of changes in different water undertakings using a comparative efficiency assessment (CEA) method (Larsson *et al.*, 2002).

Consequently, over the years beginning from 2000, Scottish water has been using benchmarking to assess its performance, relative to those of England and Wales water utilities; the areas of assessment according to Scottish Water include service levels, operating expenditure, capital maintenance and enhancement (Scottish Water, 2012).

In what is considered as fundamentals of benchmarking application, Camp (1989) captured the universally adopted Xerox's 10 – step benchmarking model which serves as basics for designing contemporary benchmarking methodologies in water utilities. They include:

1) Decide what to benchmark
2) Establish the team
3) Identify benchmarking elements
4) Identify internal data sources and methods of collection
5) Collect internal data
6) Decide external benchmarking partners
7) Collect external data
8) Analyse results and refine gap
9) Adjust goals and develop improvement plan
10) Review and re-benchmark

However, Love *et al.* (1998) have added that even as the 10 – step benchmarking model serves as an excellent outline for benchmarkers to follow, there is a pressing need to undergo intensive training on the subject, in order to clearly understand these steps.

It is noteworthy that water utility benchmarking can be likened to water audits; these two require a comprehensive assessment of an organisation’s operations and processes, including the financial and customer services. However, benchmarking goes beyond audits, in that it further seeks comparable partners and standards to gauge an organisation’s performance with the aim of implementing established best practices and improving productivity.

Whereas it is currently widely utilized in Europe, Australia, Asia and in almost all public service sectors to improve productivity, benchmarking as a concept, process or practice has become a household name in utility performance measurement and improvement, both in the water industry and other infrastructure regimes. As conceded by Paralez (1999), benchmarking *“has become one of the buzzwords of this decade and has gained popularity in many industries including public utility organisations”* (Kingdom 1998, p.1). However, notwithstanding its popularity, many organisations are hitherto yet to identify with the significance of benchmarking in enhancing their water productivity or performance.

3.1.3 Definitions of benchmarking

One of the major objectives of every benchmarking study is to provide a clear and comprehensive definition of benchmarking in order to elucidate the concept and enhance the understanding of its application as a performance improvement tool. The oldest (yet, most widely accepted) definition of benchmarking was given by Camp in 1989 as:

> *"A process of self-evaluation and self-improvement through the systematic collaborative comparison of practice and performance with competitors in order to identify own strengths and weaknesses, and learn how to adapt and improve as conditions change."* (Camp, 1989).

Further, a *"peculiar"* definition of benchmarking was given by Spendolini (1992) cited in Jackson (2001, p.220) as *"a strategy for enabling people to think outside the boxes they normally inhabit; these boxes being the organisations, services, institutions, practices, products, functional units ..."*.

These prior definitions gave way to the contemporary meaning of benchmarking as *"a tool for performance improvement through a systematic search and adaptation of leading practices"* (Cabrera *et al.* 2011, p.2) or a detailed review and comparative assessment of an organisation's performance with those of other similar organisations, so as to identify, adopt and implement established best practices (CIPFA, 1996).

A definition of benchmarking which according to Simpson and Kondouli (2000) is currently adopted by over 150 United States companies is given by the American Productivity Quality Center as follows:

> *"Benchmarking is a systematic and continuous measurement process; a process of continuously measuring and comparing an organisation's business process against business process leaders anywhere in the world to gain information which will help the organisation take action to improve its performance"* (APQC, 1993).

Theoretically, these benchmarking definitions clearly lend meaning to the idea of benchmarking by Dassler, *et al*, (2006, p.1) as a *"yardstick competition"*.

It is essential to note that the meaning of benchmarking should comprise of both qualitative and quantitative or numeric scrutiny, as a tilt towards one aspect will not give a comprehensive explanation of the benchmarking concept. On this note, an encompassing definition was developed by Baumann (2011, p.14) as *"... any beneficial reduction in water use or in water loss"*. It is noted by the author that the *"beneficial"* implies that *"the reduction in water use should give rise to a net increase in social welfare provided, where the resources used have a lesser value than those saved"*. This both depicts the relevance of economic efficiency, and underpins the significance of process benchmarking.

From the foregoing, even where a benchmarked organisation recognises itself as high performing, the substance of benchmarking in a nutshell remains that it must be considered as a learning process. As suggested by CIPFA (1996, p.2), *"it works best as* *part of a culture of constantly seeking out quality and performance improvement"*. Thus, benchmarking is a process of active research and learning, and acquisition of the requisite knowledge requires a deliberate self-evaluation process through structured and systematic activities designed to discretely reveal *"better and smatter ways"* of self-improvement and self-regulation.

3.1.4 Types of benchmarking

In principle, benchmarking types are considered distinct activities, capable of being singly adopted and applied, but in practice most benchmarking activities involve a combination of different performance evaluation aspects which actually underpin and frame the classification of the benchmarking types. A comprehensive summary of benchmarking types is posited by Camp (1998), Jackson (1998a), Jackson (1998c), Spendolini (1992), Price (1994), Alstete (1995), Schofield (1998), Appleby (1999), Jackson and Law (2000a), cited in Jackson (2001) as follows:

i. Metric data benchmarking

Simply known as metric benchmarking; this involves an assessment of the quantitative (numeric) information of an organisation. Historically, metric benchmarking emerged out of the need to measure the numeric indicators of inputs and outputs associated with business and industrial activities (Jackson, 2001). This measurement requirement is achieved through the use of Performance Indicators (PI) and metric benchmarks that are widely published by commercial institutions in the form of league tables. The IBNET toolkit is one benchmarking scheme that comprises of key performance indicators developed for metric assessment.

Suffice it that metric benchmarking helps in identifying areas where there are apparent performance gaps but does not essentially give *"an understanding of explanatory factors"* … such as physical traits, geography (location), weather, custom, extenuating factors, population, etc. (Jackson, 2001). Equally, in the opinion of Kingdom (1998, p.270), *"the quality of raw water, the topography of the area and the scale of the operation, all impact costs to different degrees and are outside the control of management … these are referred to as explanatory factors."*

Whereas metric benchmarking focuses on comparing KPIs, this method according to Cabrera *et al.* (2011) is still the assessment method used by OFWAT and a majority of water industry regulators around the world.

By using numeric values for comparison, metric benchmarking results are adjudged quantitative and precise, but numeric data in one organisation are seldom put together in the same way in other organisations. Thus, figures differ from one company to the other and may not reflect the true level of an organisation's performance efficiency relative to those of others. Reasons for numeric differences may include effects of the operating environment, an organisation's level of technological advancement, dedicated staff expertise, and data collection and/or storage methods in use, etc. On this premise, Kingdom (1998) posits that metric benchmarking basically gives a sense of relative performance.

ii. Process or bureaucratic benchmarking

Converse to the metric benchmarking approach which is objective and quantitative in nature, the process benchmarking relies greatly on textual (text-based) information. This entails comparing the qualitative or non-numeric activities of an organisation to those of high performing peer(s), and requires explicit reference to textual facts such as industry bests, specifications, benchmarks and codes of practice for its application (Jackson, 2001).

Whereas, metric benchmarking does not provide a good understanding of possible *"explanatory factors"*, process benchmarking therefore uses information resulting from metric benchmarking process as a means of determining prevailing explanatory factors and reducing or eliminating any apparent performance gap.

It is noteworthy that process benchmarking, also known as *"Xerox style"* (Kingdom, 1998) or simply: Xerox benchmarking, compares the processes and practices of selected peers. As claimed by Van den Berg (2011, p.3), it is *"a normative tool with which one utility can compare the effectiveness of its processes and procedures for carrying out different functions to those selected peers."*

Process benchmarking according to Larsson *et al.* (2002) involves: Mapping the operations and functions of an organisation to be benchmarked; Identifying high performing organisations, why they are performing so and which aspects constitute their areas of strength; and lastly, adopting or adapting (with amendments) considered best practices by the benchmarked organisation.

Process benchmarking can therefore be applied to companies with dissimilar products but similar processes; e.g. assessing clients' satisfaction in hotel and hospital sectors with catering as the common process in both.

Suffice it that among the benchmarking types, two most applied and widely researched are the metric and process benchmarking. These the IWA specialist group have recommended that they be replaced with performance assessment and performance improvement respectively and has attributed their decision to the emergence of dozens of benchmarking reports using the names *"metric"* and *"process"* benchmarking with a clear lack of consistency in the authors' applied meanings or description. However, what is most important in every benchmarking effort is its methodology, not the benchmarking name, because benchmarking is a tool; thus, a means to an end, and not an end in itself. Table 3.1 reveals a summary of other benchmarking types, their areas of application, advantages and disadvantages.

BENCHMARKING TYPE	**MEANING, APPLICATION, ADVANTAGES AND DISADVANTAGES**
Brokered Benchmarking	In this benchmarking method, the broker or consultant takes the sole responsibility of collecting the requisite data and conducting the benchmarking exercise without engaging the benchmarked partners (CIPFA, 1996). The advantage of this benchmarking type is that the broker who has the right benchmarking expertise conducts the exercise more accurately, with no bias. However, it is often expensive and requires that the broker clearly understands the processes benchmarked.
Competitive benchmarking	This entails comparing performance with competitors and requires the willingness to share information and accept any outcome as a means of enhancing performance. This benchmarking method clearly reveals how organisations are performing relative to their comparable partners. In practice, the name *"competitive"* is often avoided because most organisations do not want customers to know how they are performing relative to other similar organisations.
Regulatory benchmarking	Regulatory benchmarking is currently extensively used by different international organisations to improve performance. In Hungary, it is used for telecommunication regulation; in Netherlands, for electricity, water and telecommunications, and mainly for electricity regulation in New South Wales and Norway (Dassler et al., 2006). In the UK, monopoly and privatisation of various water utilities have necessitated the enforcement of different regulatory regimes. OFGEM *"have been leaders in developing benchmarking methods and their use among UK infrastructure regulators"* (Stern 2008, p.6). The downside to this benchmarking type is that in most cases, the outcome of this exercise is published for public access; this may negatively affect poorly performing organisations.
Generic benchmarking	Most industrial processes are repetitive and require a maintained level of standard, notwithstanding their repetitive nature. These repetitive jobs are considered as generic; thus, generic benchmarking helps to discover how organisations are able to overcome decline in productivity which is often associated with repetitive processes. It requires identifying firms with similar repetitive processes.
Independent benchmarking	Also known as non-collaborative benchmarking, it is an evaluation process that basically requires the availability and accessibility *"of a database or relevant statistics and performance indicators; ... this is conducted without involving external partners"* (Jonathan 2001, p.225). The negative part of this approach is that the benchmarked firm is often unaware of the applicable best practice from other firms.
External & Internal benchmarking	Whereas, the external benchmarking method involves comparison of performance between different firms, there is often the difficulty in identifying firms with same processes and technologies. The internal benchmarking type, also known as the in-house benchmarking is detailed to a single organisation. According to CIPFA (1999, p.8), internal benchmarking involves comparing internal processes, aimed at sharing good practice and *"particularly useful in multi-site operations."* This is normally applicable to organisations with multiple units such as multi-nationals, and involves comparing their processes against each section or branch in order to assist ailing units (Kelessidis, 2000). The demerit of internal benchmarking is that it limits the benchmarked firm to the in-house best practice.
International benchmarking	Although rarely considered as a benchmarking type, it involves comparing the performance of a firm with that of similar international or national firms. This implies that other benchmarking methods: metric, process, competitive benchmarking, etc., also constitute international benchmarking where they are used for comparing the performance of peers across nations. The disadvantage is that there is always a wide variation in the process factors affecting water use, from one country to another.

Table 3.1: Benchmarking types, their meaning and areas of application.

3.1.5 Benchmarking pitfalls

Fundamentally, inconsistency and ambiguity of concepts and definitions constitute major problems in benchmarking. For instance the proposal by IWA specialist group to replace the terms *"process"* and *"metric"* with performance assessment and improvement respectively, has met stiff oppositions by various stakeholders who uphold that the explicitness of the *"process"* and *"metric"* concepts is relatively lost in the idea of replacing same with assessment and improvement.

Similarly, a good benchmarking initiative is informed by the quality of data and information at hand. Inaccessibility or unavailability of data is identified as a key challenge to any benchmarking decision. Some accessible data do not also come in a usable form; they are either not properly collated or erroneously documented. Ideally, this is often a function of organisations' practices, policies or levels of infrastructural advancement. In practice, a dedicated staff is detailed to regularly collect, sort and store performance data that should be readily accessible at all times. This process of data management should be a fixed and continuous task; however, this is often undertaken as an adhoc exercise tailored towards an exigency such as when there is need for an audit or periodic performance evaluation.

Predominantly, most organisations are aware of the need to conduct a benchmarking assessment, but lack of professional benchmarking staff constitutes a great barrier to undertaking the benchmarking exercise (Berg, 2010).

Based on knowledge derived from the benchmarking of three projects, Love *et al.* (1998) considers the following as major causes of benchmarking failure:

a. Unrealistic assumptions or excessively wide benchmarking subject

Benchmarking assessment planning should be as pragmatic as possible. Intended plans should be reasonably verified and certified as realizable. This often requires looking up how similar organisations conducted benchmarking on their utilities, what pitfalls or shortfalls they had, and where and how best to avoid same.

Where benchmarking processes are clearly more than what the team can handle, it may be inferred that the scope or benchmarking subject is practically unrealistic. It must be confirmed that the scope can be completely covered. This will help keep the benchmarking process in check and enable completion of the benchmarking task within the given time and cost.

b. Insufficient benchmarking project definition

Where team members are not clarified on what they are to measure and what not, they end up making arbitrary decisions and probably becoming resource inefficient. This may make the project lack the required focus and direction for proper execution of the task. Even when results are produced in such circumstance, it may be considered invalid given that the team is seen as technically unfit to undertake the task in the first place. The question: *"How do we carry out this task?"* should be anticipated during the training or briefing session. The answer is then meant to encapsulate a detailed explanation of the steps required for each process, and enable knowledge transfer among the benchmarking team members.

c. Absence of dedicated benchmarking staff

Where a member of the benchmarked organisation is part of the benchmarking exercise, it is necessary that the staff is relieved of other roles that may influence conducting the assessment with reasonable focus. In practice, a staff is to be categorized as *"dedicated"* specifically for the benchmarking exercise.

3.1.6 Beneficiaries of water benchmarking

A comprehensive explanation of potential beneficiaries of the water benchmarking exercise has been detailed by Alegre *et al.* (2006) as follows:

i. Water undertakings

These include the public, private or some combined entities who manage water supply systems. In the UK, England and Wales has 10 Water and Sewerage companies and 13 water only companies, while Scotland and Northern Ireland each has 1 water and Sewerage Company. And these periodically review their performance in a view to determine grey areas or areas of potential resource (financial, energy, water, etc.) savings.

ii. The consumer or direct users

The direct users are supplied by the water undertakings and take the responsibility of paying their service rates; although, some consumers abstract directly, having paid the abstraction license. In the case of directly abstracting, such water is often used for specific purposes not requiring treatment, or treating the water themselves where necessary.

iii. *The indirect stakeholders*

These do not have a direct link with the water supply but could be affected by processes of water undertakings in the form of impacts on the immediate environment due to excessive abstractions (in quantitative and qualitative terms) or water mains burst(s).

iv. *Proactive stakeholders*

This group includes consumer protection, environmental organisations such as SEPA, EPA, SNH, etc. and other pressure groups. They monitor the quality of the national heritage or environment and ensure the ecological habitats are not destroyed.

v. *Regulatory Agencies*

They regulate quality of services and economic obligations of parties involved in water processes, hence ensuring compliance.

vi. *Policymaking bodies*

They are comprised of governments and parliamentary arms who decide at various levels the statutory obligations of different water related groups. These decisions are implemented by the pro-active stakeholders and regulatory agencies.

vii. *Financing agencies*

Financing agencies demonstrate some level of financial commitment with a view to achieving a predefined target. These targets often vary, but are usually associated with effective, efficient and sustainable practices that should lead to optimal performance in concerned sectors. According to Alegre *et al.* (2006), financing agencies may include: international organisations, multinational agencies, humanitarian associations, NGOs and political organisations.

3.1.7 Benefits of water benchmarking (Expected outcomes)

Driven by the need for accountability, transparency and standardized information for performance comparison, benchmarking has globally gained prominence and its use has been widely recognised as a strategy for improving productivity and gaining market competitiveness (Van den Berg, 2011).

Benchmarking is considered as an indispensable tool for boosting performance, a means of enhancing the sustainability signature of concerned organisations and one sure way of fostering investment decisions. The use of benchmarking to evaluate comparative information has become a key management tool for utility managers, regulatory agencies and professionals in water utility. As asserted by IBNET (2013, p.3),

> *"benchmarking helps water and sanitation utilities find comparators for identifying and sharing best practices, new knowledge, and in ensuring that nothing is missed in the important job of delivering water and sanitation services to their customers"* (IBNET, 2013 p.3).

Benchmarking also enables both performance improvement and sound utility governance (Bangladesh Water Utilities, 2009). It enhances competitiveness in business, through *"providing the highest quality of service at the lowest cost"* (CIPFA 1999, p.6), and rationalises the use of scarce resources for an optimal productivity (Van den Berg, 2011).

In the opinion of Kelessidis (2000, p.4) benchmarking *"accelerates change and restructuring through applying tested and proven practices, convincing sceptics, overcoming inertia and complacency, and creating a sense of urgency when gaps are revealed."*

Benchmarking enables managers to clearly understand their utility performance status relative to others and enhances sharing of knowledge, best practice information and methods, in order to improve performance (IBNET, 2013). It explains how well an organization has been performing and helps in projecting future performance. It is noteworthy that national, state and municipal regulators whose responsibility it is to set policy priorities need to know how operators are performing in relative terms (Berg, 2010). Thus, a clear understanding of how comparable organisations are performing will help in identifying their performance peaks. An excellent performance score should provide a yardstick for gauging other organisation's productivity, thus designating the concerned organisation as a benchmark organisation.

In explicit terms, benchmarking helps in achieving the following:

- Enhancement of a greater understanding of an organisation's performance against best practices.
- Identification of areas where remedial actions are greatly required for resource savings
- Promoting doing things *"outside the box"* by identifying other improvement strategies beyond an organisation's scope (Kelessidis, 2000)
- Ease of setting out and monitoring of realistic or achievable targets (Bosteels *et al.*, 2010)

- Assessment of environmental impact of a process, practice or product.
- Improving asset value (Bosteels *et al*., 2010)
- Healthy performance comparison between organisations with similar process, practices or products.
- Avoiding reinventing the wheel: Why invest in or waste useful resource (time, talent or treasure) to discover what another organisation has long discovered and applied? (Kelessidis, 2000)
- Assisting *"legislative and regulatory compliance"* (Bosteels *et al*. 2010, p.8)

Thus, implementation of benchmarking results or changes is known to enhance significant improvement in processes, practices or performance.

3.2 Composition of a Typical Benchmarking Strategy: Benchmarks, Metrics, and Key Performance Indicators

3.2.1 Synopsis

The use of metrics, benchmarks and KPIs to measure and compare performance is a long standing practice in the water industry. *Ab initio*, the inconsistent definition of terms, processes and practices has remarkably affected the water industry's ability to establish utilities performance through measurement, comparison and standardization (Dziegielewski and Kiefer, 2010).

Notably, assessing a utility's water use over a period of time is a great task, yet this becomes even more complicated following the lack of standardized and conventionally adopted terms for different categories of water processes and practices. There is therefore the need to carefully define the water use concepts for an explicit assessment of utilities performance. First, a distinction must be established between water use and water consumed. Water use has been defined in the engineering context as *"the amount of finished drinking water produced or sold to customers through metered connection"*, while water consumption designates water sold out (Dziegielewski and Kiefer, 2010). However, in principle, such definitions do not exhaustively provide the requisite meaning; rather, it depicts a policy or practice specific to an organisation. It is on this note that the generic meaning of water use as water used for practical purposes (consumptive or non-consumptive) is accepted for this study.

3.2.2 Metrics

Simply put, a metric is a unit of measurement or parameter being measured that can be used to assess the rate of water use during a given period of time and level of data aggregation; or the difference between total water produced and total metered sales, currently referred to as nonrevenue water (Dziegielewski and Kiefer, 2010).

Whereas, units of measurements are derivatives of formulas (i.e. in the context of derived units) it therefore rightly applies that metrics are formulas which can be used to deduce the performance of processes in numeric terms.

In terms of water use, Dziegielewski and Kiefer (2010) proposed that metrics are generally calculated as usage ratios or quotients calculated by dividing the volume of water used (or sold) over a given duration (day, week, month, season or year) by a scaling factor (e.g. number of accounts, population served, or number of housing units or employees). A metric value is the derived numeric quotient of a utility which denotes its performance. This therefore explains why metrics are also considered as performance indicators. The quotient gotten therefore depicts the numeric performance of a utility which can then be compared with an existing benchmark in order to evaluate the relative performance level of the utility under assessment.

3.2.3 Performance Indicators (PIs) / Key Performance Indicators (KPIs)

In the opinion of Van den Berg (2011, p.3), PIs are the building blocks for any benchmarking strategy and constitute *"quantitative, comparable measurements of a specific type of activity or output."* Being an absolute measure of performance, PI's basically suggest or reveal areas *"where performance might need to be investigated"* (CIPFA, 1996, p.11). Thus, they provide the needed information on whether or not a performance assessment should be conducted on a utility. According to Alegre *et al.* (2006), Performance Indicators are measures of the efficiency and effectiveness of services by an undertaking, which results from the combination of several variables. These variables according to the authors are data elements measured from the field or deduced from standards that can be combined into processing rules in order to define performance. Further, as contained in the report by WRAP (2013a, p.9), *"KPIs are financial and nonfinancial measures that can be used to help a business define and evaluate how successful it is, typically in terms of making progress towards its long-term organisational goals"* … and these *"KPIs are essential to any successful benchmarking campaign."*

It is also worthy of note that the international benchmarking network for water and sanitation utilities (IBNET) developed a toolkit which provides a set of process, monetary and technical indicators for assessing the performance levels of water and wastewater services among utilities of different countries.

Performance indicators are very useful in metric benchmarking because as predetermined targets, they aid quantitative performance comparisons (Larsson et al, 2002); however, to examine business processes, the process benchmarking is best suited. Although, Alegre *et al*. (2010), have surmised that key PIs include: Water Resources (WR), Personnel (Pe), Physical (Ph), Operational (Op), Quality of Services (Qs), Economic and Financial (EF), but these indicators do not provide the ratios or metrics for comparison. Against this milieu, Kingdom (1998, p.270) gave a summary of water utility Key Performance Indicators (KPIs) that can be adopted for benchmarking comparison exercises as follows:

1. Average Cost Indicators (Cost/m^3 of treated water)
2. Efficiency indicators (Bills processed / staff / hour)
3. Time related indicators (Time to process a telephone enquiry)
4. Quality of service indicators (availability, quality of water, pressure)
5. Explanatory factors (Scale of operation, inherited assets)

Further, WRAP (2013a) produced a summary of the key industrial water use KPIs, their corresponding units (metrics) and concise description of their application strategies (see Table 3.2).

KPI	Metric (Unit)	What is it?	What does it reflect?	What is good?
Total water (absolute)	m^3	Total water use on site.	Total volume of water consumed in any given time period (week, month or year).	Low levels.
Total water (relative to production)	m^3/tonne of product	Total water use on site.	Total volume of water consumed in any given time period (week, month or year) per tonne product.	Will depend on particular product and production related water use.
Consumptive water	m^3	Total water use on site, excluding cooling water extracted and returned to source.	Volume of water consumed in any given time period (week, month or year).	Low levels.
Process water (absolute)	m^3	Water used in processing operations, including that used as a raw material (ingredient).	Volume of water used in any given time period (week, month or year)	Low levels.
Process water (relative to production)	m^3/tonne of product	Water used in processing operations (including that used as a raw material - ingredient) per unit of product.	Volume of water used in any given time period (week, month or year) to produce a normalised unit of production.	Will depend on particular product and production related water use.
Cleaning water	m^3	Water used for cleaning purposes.	May be difficult to determine as process water is often used for cleaning and sourced from a number of areas (cleaning-in-place (CIP), hoses, hygiene stations) that are not sub-metered.	Low levels, generally good.
Cooling water	m^3	Water used as a coolant (where applicable).	May be difficult to determine as process water may be used for cooling and may not be separately sub-metered.	Low levels generally good.
Water re-use	% (by volume)	Proportion of water re-used on site (e.g. hot process water re-used for fluming raw materials or for cleaning) as a percentage of the total water consumed.	Level of water re-use being achieved.	High levels, good, but could mask inefficient processes or practices leading to excessive water use in the first place.

Table 3.2: Major industrial water use KPIs and metrics, with their application descriptions

Adapted from: WRAP (2013b, p.11)

In practice, water usage is quantified either based on total volume or in terms of production, that is, normalized volume (BIER 2011, p.14). The total volume is often related to water use per period of time such as L or m^3 / annum. Normalized volume on the other hand is associated with water use per unit or per volume of product or output, e.g. L or m^3/L or kg or kW etc.

3.2.4 Benchmarks

Benchmark as a term was originally applied in surveying to mean a survey peg, datum or mark, normally as a permanent reference point against which levels of various topographic features of the earth can be readily measured (Jackson, 2001 and Bosteels *et al.*, 2010). This concept later gained prominence in the social sciences as a yardstick for measuring performance through comparison. Numerous authors have reckoned with the idea of benchmarks denoting criterion or reference or mark of distinction in products or even best practices or services (CIPFA, 1999; Jackson, 2001 and Bosteels *et al.*, 2010). These reference points according to Bosteels *et al.* (2010, p.4), can either be based on targets, averages or percentiles of any set performance or even policy-driven objectives like the *"net zero carbon."*

Therefore, it may be said that a benchmark is a predefined value used for measuring a utility's performance. Benchmarks are either absolute or relative or even unitless (Dziegielewski and Kiefer, 2010). Absolute benchmarks come in the form of per capita water use/day which is exact, while relative benchmarks manifest in the form of water conservation or reduction strategies like 30% per capita water use reduction by 2014. Unitless benchmarks such as ratios and percentages represent relative benchmarks and are often target values. According to Kuntele *et al*., (2003) cited in Dziegielewski and Kiefer (2010), an example of an absolute water benchmark is the Infrastructure Leakage Index (ILI) which is defined as the ratio of yearly water losses during transmission and distribution to an estimated value of unavoidable leakage.

Therefore, benchmarks are numerical values or quantitative measures for comparing performance and identifying where more detailed review of organisational practices or processes are required, while benchmarking is the process of carrying out this exercise.

Whether termed performance indicators or standards or cost ratios or statistics or best practice guides, these are all benchmarks (CIPFA, 1999). However, as governments and regulatory agencies continue to review the operational directives or regulations, older benchmarks become *"not applicable"* and require updating. It is a different case where organisations do not have existing benchmarks to measure their performance(s). In such cases, they need to create or develop new benchmarks becomes necessary.

3.2.5 Performance measurement, monitoring and management

In the field of water, various authors have in theory confused the distinction between performance measurement, monitoring and management. Literally, performance measurement entails gauging a process or practice. This does not necessarily need to be metered or measured against other gauged processes; it only reveals an organisation's performance either numerically or textually through assessing its inputs or outputs. On the other hand, whereas organisations set specific performance goals or targets for a given activity, the process of assessing their performance against pre-determined standards or measures is called performance monitoring (CIPFA 1996, p.12). However, beyond performance measurement and monitoring is the management. Performance management according to CIPFA (1996, p.12) *"stems from the desire to improve and willingness to embrace new processes, strategies, structures, cultures and different responsibilities."* Benchmarking, which is basically a learning process rather than just gathering data and information, must be aimed at seeking a change with an *"open mind"*. It is not a defensive process and is not approached with the mind-set of competition or plan to emerge the best.

Organisations often undertake the exercise of comparing their products and processes against those of similar organisations without actually labelling the process *"benchmarking"*; conversely, some other organisations undertake benchmarking only to establish the performance status of their organisations for periodic reports without a structured plan to improve their performance. However, CIPFA (1996) has argued that benchmarking works well only where the process is for self-improvement through commitment to making change and not merely a practice to deduce how an organisation is performing.

This brings to bear, the understanding of the concept of performance measurement and management. *"Measurement is passive, whereas management is active."* Thus, since benchmarking focuses on improving performance through continually assessing processes to identify best practices, it is an *"active management of performance"* (CIPFA, 1996, p.11).

To this end, areas worth considering when conducting a benchmarking exercise may include:

- Areas with high resource (energy, water, cash, time, etc.) use;
- Areas most criticized;
- Areas where measured and compared performance results are relatively poor.

3.3 Benchmarking Application

3.3.1 Setting the stage

In the water industry, benchmarking strategies largely vary from simple unit cost comparison to complex mathematical methodologies; and even in sophisticated benchmarking processes, it is good practice to start from the simple aspects before advancing into compound models which often become confusing where requisite rudiments are not well understood (Bosteels *et al*,. 2010).

Further, it is pertinent to state that benchmarking is not a start – finish process as considered in project management ideals; rather, it is a systematic, continuous process which requires regular reviews to meet the requirements and standards of various stakeholders. As pointed out by Cabrera *et al.* (2011) benchmarking is a plan-do-check-act process because what was considered as best practice yesterday may be classified as inefficient today. Thus, there is need for dynamism in carrying out any benchmarking exercise.

Benchmarking must not be seen as comparison of organisations' performance with the aim of ranging their productivity from worst to best. It is rather a management tool which helps in highlighting the performance status of an organisation, with the aim of enhancing its productivity.

To this end, Larsson *et al.* (2002) have streamlined the steps of any benchmarking application process to include the following:

1) Definition of component activities
2) Clearly identifying the objects to compare
3) Constitution of the benchmarking Partners
4) Development of Key Performance Indicators (KPI's)
5) Deduction of predominant performance gaps
6) Selection of assessment methodologies or models of data analysis
7) Assessment and implementation of the benchmarking results for performance improvement.

3.3.2 Benchmarking Criteria

A critical examination of the benchmarking steps above, reveal that essential requirements or criteria for an effective benchmarking include: the need for self-evaluation, selection of benchmarking partners and identification or deduction of references or benchmarks. Jackson (2001) strongly maintained that benchmarking can be viewed from just two broad spectra: dialogical – involving active research and discussion between participates; and bureaucratic – which mainly encompasses the process of references against standards, specifications, codes of practice, industrial benchmarks, exemplars, company bests or best practices, performance criteria or metric data.

Also known as yardstick competition, benchmarking is not a process geared towards digging out the past and present performance of an organisation, but one aimed at establishing an organisation's performance against a yardstick or optimal performance level.

In assessing organisations' performance, utilities with similar processes are compared. Although each utility is in itself unique, in selecting benchmarking participants, it is important to confirm that the considered utilities have processes, circumstances and practices that are reasonably similar. This similarity requirement has been considered indispensable in benchmarking, as the outcome of any benchmarking exercise on organisations with dissimilar processes can be contested on grounds of not comparing *"like – with – like"* (Scottish Water, 2012). Accordingly, there is the need to identify *"best of the bests"* companies to benchmark with.

3.3.3 Benchmarking Planning

Before conducting any benchmarking exercise on a facility or utility, the objectives and methodology of work must be clear to all staff. Whereas, most organisations do not have dedicated department or staff for benchmarking exercises, there may therefore be need for staff training on collection, categorisation and assessment of benchmarking data. Depending on the benchmarking type, the staff composition may include the participating organisations or be limited to the benchmarking consultant (where this is handled exclusively by a third party). As reckoned by Cabrera *et al.* (2011), the possible roles may include being part of the expert group (playing an active role) or the benchmarked reference.

In planning benchmarking assessment, the team initially tries to work out what the possible areas of concern or performance gaps of the participating organisations could be. This should lead to drafting or mapping of a work programme which normally depicts aspects of the utility to be benchmarked, why such areas are selected and possible roles to be taken up by interest groups. Then the working document including the code of conduct is sent out to identify interested utilities with similar organisational or operational structure. When a considered substantial number of utilities accept to participate, then the training or orientation process commences.

3.3.4 Selecting benchmarking partners

The first step to any benchmarking comparison planning is the identification and selection of high performing partners. Before proceeding to prospective benchmarking partners, there is need to investigate what the processes and performance of these organisations are. Such information should be available in the public domain, *inter alia*: industry journals, Total Quality Management (TQM) groups and benchmarking associations (Kingdom, 1998). More so, in choosing these partners, it is key to consider the ease of access to the company's performance data (CPFA, 1999). There is the natural reticent by any organisation to give in to assessment or comparison of its performance. This constitutes a great barrier to executing benchmarking, but can be minimised where the intention is clearly specified; for instance, stating that the intention is to improve on performance through learning.

Although benchmarking seeks to identify the best – in – class, but in the actual sense, lessons can be learnt from most organisations because companies have areas or aspects where they perform remarkably. This could be in their administrative, process or technical practices. It therefore applies that benchmarking seeks to identify areas of strength in any organisation through comparison.

In practice, benchmarking always seeks the *"best – in – class"* and any organisation in this class is classified as a benchmark organization. Thus, *"a benchmark organisation is one that is widely recognized for achieving standards of performance on key indicators that others agree to and measure themselves against"* (Kelessidis 2000, p.6). However, there are prevalent difficulties associated with identifying best – in – class organisations, because organisations with acclaimed best practices or processes often receive loads of benchmarking invitations. Thus, there is the possibility that some requests to benchmark may be turned down. Also, application of results gotten from benchmarking against company bests may necessitate a quantum leap, rather than incremental changes and such lessons may then become difficult or even impossible to implement (Kelessidis, 2000).

The conviction to be benchmarked against is best facilitated by the provision of a benchmarking performance incentive. According to Berg (2010), this may come in the form of statements such as: *"studies have shown that through benchmarking, organisations have been able to improve performance overtime and avoid falling efficiency ratings".*

Although, there is actually no clear cut threshold or yardstick for determining who should or should not be benchmarked, however, where organisations tick similar boxes, the benchmarking exercise can be carried out believing that there is substantial common ground to conduct the assessment. The aim must be borne in mind: to highlight grey areas. It is on this premise that Cabrera *et al.* (2011, p.36) posited that benchmarking is actually not about producing perfect comparisons … *"but identifying performance gaps, best practices and improvement opportunities ... even without perfect comparisons."*

3.3.5 Benchmarking data management (collection, validation and analysis)

Data collection is acclaimed the most time-intensive process in benchmarking, and the success of this activity is always a function of the data availability and accessibility. When data is finally acquired, the next step is to ascertain its accuracy and usability. The former requires closely examining the data for consistency and where the data is considered inconsistent, fresh data may necessarily be sought; but, where the fresh data is still inconsistent, it must be discarded. Thus, data will be categorized as valid or invalid based on its accuracy and usability for the benchmarking analysis.

After validating benchmarking data, the next activity is to analyse it. The analysis process requires accessing available PIs or benchmarks or metrics, or deducing one for the comparative assessment. Some organisations have benchmarks or PIs in their repository which can be accessed; however, the available benchmarks or PIs may not be applicable to the task at hand, hence requiring recalculation of new ones. A conventional way of calculating or developing benchmarks or PIs is through the use of metrics.

When the comparison benchmarks or PIs are available for use, the decision of what analysis tool to use follows accordingly. Although, most benchmarking assessments in the water sector use simple spreadsheets or general multipurpose programs (Cabrera *et al.*, 2002), few software applications are water utility specific. These software programs used for water benchmarking analysis are either bespoke (tailor-made) or standard. For water benchmarking, SIGMA is developed by Instituto Tecnologico del Aqua; its standard version is the SIGMA Pro while the free version is Sigma Lite.

3.3.6 Benchmarking assessment reporting

According to Cerebra *et al*. (2002), the first result of a benchmarking exercise is considered as a draft report. This report is then used for preliminary discussion aimed at identifying errors and performance gaps. This finally either leads to benchmarking re-assessment or drafting of final report.

The final report is to reflect the identified performance gaps and to map out potential improvement actions. This report will then be disseminated to the benchmarked organisations.

3.3.7 Implementation of performance improvement actions

The implementation process is considered as a crucial stage in every benchmarking process as it requires the input of participating utilities in a workshop setting. At this point, it is expected that all benchmarking parties will agree on key identified improvement opportunities. Considered as *"taking theory into action"*, the senior utility management shall approve the necessary changes *"and draft an improvement plan to implement the changes"* (Cabrera *et al.*, 2011). A dedicated staff is then appointed by the senior utility management to oversee the implementation of the improvement plans.

3.3.8 Performance improvement plan review

This action is referred to as closing the loop, and takes the form of re-measuring the extent to which previously learnt lessons are implemented, or undertaking an entirely new benchmarking exercise (Cabrera *et al.*, 2011). However, this stage shall be heralded by a cause analysis to determine why some organisations outperform others and what lessons can be learnt. Then the review results shall be documented for future comparisons.

3.3.9 Knowledge and experience sharing

Knowledge is either written (Captured) or tacit. The former can be assessed where permission is granted, but the later (tacit knowledge) resides in the individual whose unwillingness to share a considered requisite knowledge means outright information denial.

Ideally, so much can be learnt from any utility personnel with an open mind to the benchmarking initiative (Cabrera *et al.*, 2011). The open-mindedness in this context does not imply flippancy, rather willingness to share and make meaningful contributions based on an individual/organisation's experience or understanding of a process or concept.

However, in sharing information, a memorandum of understanding or guide or code of practice / conduct must be put in place to delineate each party's roles and responsibility.

3.3.10 Benchmarking Code of conduct

Trust and confidentiality are hallmarks of any successful benchmarking exercise. Although any effective benchmarking requires a good level of professional attitude towards data and knowledge sharing, but to ensure that all parties understand and are happy with the processes and results, a guideline or protocol which spells out the operative terms will be required (Cabrera *et al.*, 2011). This guide is referred to as code of conduct. It ensures that the confidentiality of participants are not encroached, thus maintaining fair-play. The code of conduct must contain clear and concise definition of terms and conditions. A typical example is shown in Appendix D, subsection 11.1.

3.3.11 Industrial water benchmarking assessment model or process mapping

The benchmarking process is heralded by defining the benchmarking object (utility) and designing the application parameters that will aid the development of performance indicators (Rapp, 2004). The design of an assessment model to map the type of benchmarking to be conducted, the areas to be analysed, the degree of details required and the assessment tools (KPIs) to be applied is key to any successful benchmarking exercise (Cabrera *et al.*, 2011). Figure 3.1 shows a typical stepwise process mapping for industrial water benchmarking.

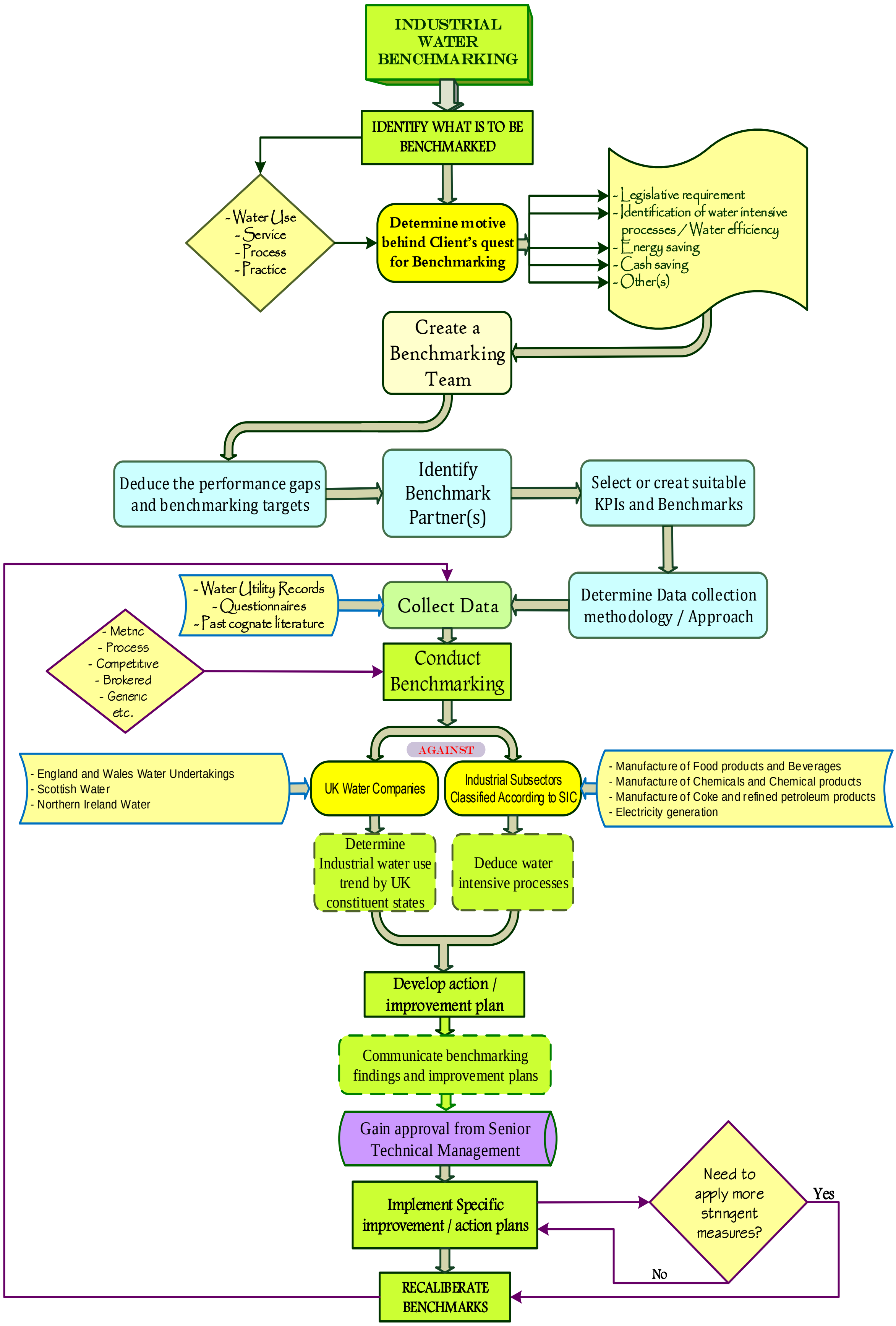


Figure 3.1: Stepwise process mapping for industrial water benchmarking

Chapter Four

4.0 Introduction

Occupying the first place in any research description, data collection, collation and analysis is a clear understanding of the underlying principle(s) behind each concept or process. This chapter thus gives a clear-cut explanation of the guiding principles of setting objective theories, *"handling"* of data and interpretation of results. In this section, the adopted research methodology, approach, design and methods are detailed. Further, this segment aims to explicate the three philosophical research thoughts, *inter alia:* paradigm, ontology and epistemology of research. It is hence considered that a clear insight into these research strategies will succinctly define the yardstick for performance measurements and establish requisite decision rules for drawing inferences based on the assessment results.

4.1 Research Methodology

A stratified approach to understanding the meaning of research methodology has been developed by Sanders *et al.* (2009) in their concept of research *"onion"* (see figure 4.1). The first stratum of the research onion is the philosophy behind the research (Sanders *et al.*, 2009); this in the view of the authors is the overarching concept of seeking to answer specific research questions, aimed at developing new knowledge or understanding existing theories. But achieving this end entails applying a set of systematic principles that should serve as the research roadmap; this is referred to as the research methodology. Research methodology as defined by Remenyi *et al.* (2003) is the *"overall approach to a problem which could be put into practice in a research process, from the theoretical underpinning to the collection and analysis of data"*; whereas, in the opinion of Fellows and Liu (2009, p. 30), research methodology *"describes the principles and procedures of logical thought processes applied to scientific investigations"*. Stated simply, research methodology is the *"overall approach to the entire process of the research study"* (Collis and Hussey, 2009). It answers the question *"how?"* and provides the means to pre-set goals and captures underlying facts and assumptions that inform the reasoning behind the research. Thus, research methodology encapsulates a set of strategic actions that range from the plan to undertake a research, through a set of systematic procedures and broad assumptions, to detailed methods of collecting and analysing data, interpreting results and presentation of findings (Creswell, 2014). Further, each research action is informed by a rationale (e.g. a researcher's experience or from some philosophical theories) and accomplished through some applicable methodological techniques or procedures. As proposed by Creswell (2014), the decision to conduct a research is informed by philosophical assumptions, set procedures of enquiry (also known as research design) and discrete research methods of data collection, collation, analysis and construal of results. In specific terms, this process of research construction that presents the research knowledge or information flow in a successive manner, from broad principles to narrow or specific theories, denotes the research methodology.

It is however inferred that a comprehensive definition of the research methodology entails an in-depth description or understanding of the four research perspectives, including the research philosophy, research approaches, research designs and research methods (Yin, 2009; Fellows and Liu, 2009 and Creswell, 2014).

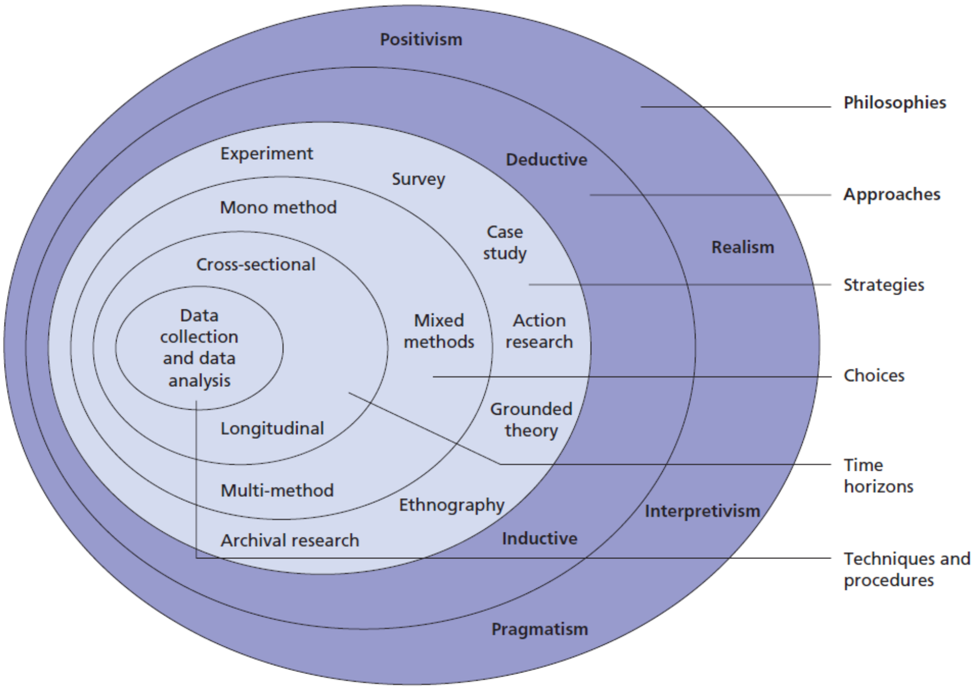


Figure 4.1: The research *"Onion"*

Source: Saunders et al., (2009, p.108)

4.2 Research Philosophy

Several authors have explained the concept of research philosophy under two major schools of thoughts: epistemology and ontology (Burrell and Morgan; 1979; Thomas, 2004; Sanders *et al.*, 2009). However, Johnson *et al.* (1984) considers the inclusion of *"paradigm"* as a more comprehensive approach to describing the philosophical concept, as revealed in table 4.1. As put forward by Thomas (2004), understanding the underlying principles behind the epistemological and ontological philosophy will assist in putting the research into proper perspective and ensuring that unsuitable claims or overestimation of research outcomes are avoided on grounds of truth, certainty and universality.

PARADIGM	ONTOLOGY	EPISTEMOLOGY
Substantialism	Realist	Objectivist
Subjectivism	Nominalist	Subjectivist
Empiricism	Realist	Subjectivist
Rationalism	Nominalist	Objectivist

Table 4.1: Research philosophical thoughts

Adapted from: Johnson et al. (1984)

Epistemology provides the requisite link between the researcher and the research; it constitutes the acceptable knowledge and establishes the milieu for knowing (Sanders *et al.* 2009; Burrell and Morgan, 1979). Further, it gives a general set of assumptions about the most suitable ways of investigating into the nature of the world (Easterby-Smith *et al.* 2008).

Accordingly, ontology is concerned with the perspectives or belief or nature of reality (Knight *et al.*, 2009; Sanders *et al.* 2009), or of phenomena (Flew, 1984). As reckoned by Burrell and Morgan (1979), two ontological assumptions exist: realism and nominalism. In describing the doctrine of realism, Sanders *et al.* (2009) asserted that *"what the senses show us as reality is the truth, and that objects have existence independent of the human mind"*; this position is incidental to the concept of nominalism which considers naturalism (or realism) as an function of the metaphysical constructs. Thus, nominalism is seen as simply a product of our minds, which implies that truth depends on who establishes it (Easterby-Smith *et al.* 2008).

Paradigm which is the third philosophical thought is described as a way of classifying a body of complex worldviews and beliefs. This in social science includes: positivism, interpretivism, post-positivism, postmodern and critical (Blaxter *et al.*, 2010).

Positivism is concerned with the use of philosophical methods and logic of physical science to reveal the laws and regulations which govern examined phenomena (Bailey, 2008; Easterby-Smith *et al.* 2008; Burrell and Morgan, 1979); hence, it is related to the nomothetics or natural sciences which aim at assessing the realistic world in a natural manner, by using objective data (Creswell, 2009). Positivism is measurable and objective, its ontology is realism; quantitative research is a typical example of this paradigm (Blaxter *et al*., 2010). However, positivism has been criticized as being unable to generate dependable explanation in an open social system (Ventovuori, 2007). A related view is shared by Fellows and Liu (1997) in their consideration that the quantitative research is unsuitable *"for unbounded research problems in which the integral variables are not known and cannot be hypothesized with relatively high confidence"* (Fellows and Liu, 1997).

In contrast, interpretivism views uphold that there is no natural basis for knowledge since all observations are value and theory driven (Burrell and Morgan, 1979). It perceives the social world as categorically consequential and historically located (Blaxter *et al*., 2010). It suffices to say that the ontology of interpritivism is realism which is both contextual and subjective. Qualitative research constitutes a good example of this paradigm type (Fellows and Liu, 2009).

Further, post-positivism is viewed *"as a response to criticisms made against positivism"* (Blaxter *et al*., 2010); postmodernists aim to overcome the boundaries between social science and art; while *"critical"* views interpretivism and positivism as a means of understanding the social world (Blaxter *et al*., 2010, p. 62).

From the foregoing, research philosophy presents itself as a principle of proposing cognate questions with the aim of creating specific research roadmaps through answering the questions. Extracting the qualitative and quantitative research approaches as such research pathways, the succeeding sections are set to detail their significances and outline their application procedures.

4.3 Research Approaches

Several authors have strongly suggested that there are mainly three research approaches including: the quantitative, qualitative and mixed methods of research (Burrell and Morgan, 1979; Fellows and Liu, 1997; Blaxter *et al*., 2010 & Creswell, 2014). While most literature consider these approaches as being relatively seamless, Newman and Benz (1998, cited in Creswell, 2014) argues that in ideal terms, the quantitative and qualitative approaches should not be seen as dichotomies or polar ends; rather, they should be considered as ends in continuum. To this Creswell (2014) opines that the mix method of research which incorporates the components of the qualitative and quantitative approaches is thus located in the centre of the continuum.

However, this position does not eliminate the fact that clear-cut distinctions exist between the quantitative and qualitative research approaches. Thus, in its barest sense, these differences are mainly identified with the use of numbers (quantitative) rather than the use of words (qualitative); or using open-ended questions (qualitative interview questions) rather than closed-ended questions (quantitative hypothesis) (Creswell, 2014).

As highlighted by Creswell (2014), in historical terms, the evolution of quantitative forms of research in social sciences became evident from the late 19th century, through mid-20th century; whereas, interests in and dominance of the qualitative approach, alongside the proliferation of the mixed method of research increased in the latter half of the 20th century. With these descriptive and background information, the three research approaches can be detailed as follows: Quantitative, Qualitative and the mix method of research.

4.3.1 The Quantitative, Qualitative and Mixed research approach

Considered as research approach (Creswell, 2014), research strategy (Bryman, 2012 and Saunders *et al.,* 2009) or research paradigms (Johnson & Christensen, 2014), decades of research by several authors to create a clear-cut distinction between the quantitative, qualitative and mixed research has resulted in the polemic expressions of thoughts rippled across the teeming studies associated with meaning of research (Creswell, 2009; Denzin and Lincoln, 2011 and Johnson & Christensen, 2014). A major cause of this divergence in choice of terminology could be reasonably traced to the adoption of words in the literal or general sense of it; that is, neither approach nor strategy or paradigms is actually a research-specific term. Thus, their application in this context denotes an adoption of their literal meanings in the field of research.

Quantitative researches in the opinion of Fellows and Liu (1997) seek to congregate realistic data and to determine relationships existing between facts, and how such facts relate to the theories and findings of other previously conducted researches.

Principally, the quantitative approach encapsulates two major statistical activities: testing of objective theories and investigation into the relationship among variables (Creswell. 2014). The quantitative method is employed to explore relationships between data variables (Creswell, 2009). This strategy was first developed in the natural sciences to study natural phenomenon by collecting and inspecting factual data (quantitative) in order to establish *"study correlations between facts and its relationships with theories and findings of previous research"* (Fellows *et al.,* 2003; Myers & Avison, 2002; Robson, 2002).

Major strengths or merits of the quantitative research include: its objectivity, precision and measurability. Although, its demerit is that it is particularly unable to profoundly explain its analysis results to the point that the qualitative approach will. Consequent on this, Fellows and Liu (1997) are of the opinion that *"it is unsuitable for 'unbounded' research problems in which the integral variables are not known and cannot be hypothesized with relatively high confidence"*.

As posited by Creswell (2014), data collection using this approach is done mainly on *"instrument"* – this helps to ensure that the data are *"numbered"*, hence can be statistically analysed. According to the author, the final written report follows a given set structure: introduction of the subject, review of past literature, identification of problems or gaps, development of theories, application of statistical methods, deduction of results and discussion of findings.

On the other hand, although there is no unified definition for qualitative research (Snape and Spencer, 2014; and Denzin and Lincoln, 2011), it involves exploring and trying to understand human and social problems through the process of proposing research questions, setting out feasible statistical procedures, collection of data via investigation of a setting, data analysis and interpretation of results (Creswell, 2014).

As a research strategy, Bryman (2012) defines the qualitative research as an approach that focuses on words in lieu of quantification; it encapsulates the procedures of discerning how the social meaning is interpreted and emphasises the link between the investigator and the *"investigated"* (Denzin and Lincoln, 2011). Qualitative research approach is best applied when the knowledge of a particular phenomenon or topic is very little or limited; this is because the strategy enables the researcher discover and learn more about the research area through the generation of new theories and hypothesis (Johnson & Christensen, 2014). Consistent with these descriptions, studies by Snape and Spencer (2014) reveal that the qualitative research is starkly a naturalistic and interpretive research strategy which is inclined towards understanding the connotations people give as information/data within the social locale. Thus, the qualitative research is considered as a means of gaining a profounder understanding of the social domain (or an unbounded milieu); its data is sourced through an interactive or discursive instrument such as interviews and questionnaires, and its ultimate aim is to herald possible exploration or emergence of new issues within the ambit of the subject under investigation (Mack *et al.*, 2005; Snape and Spencer, 2014).

However, while the qualitative approach is accorded the credence of enabling a deeper understanding of a social subject, its element of flexibility has been considered as a downside to its methods. For instance questionnaire survey has been criticized as being inclusive either based on the inability of respondents to understand the questions, hence under/overstate their opinion. This situation according to Mark *et al.,* (2005) requires that respondents should have a very clear understanding of each question.

It can therefore be inferred that an element of inflexibility can be attributed to the quantitative research approach (which makes its strategy closed-ended) and analysis of its data fairly more structured than in the case of the qualitative research where data are mainly encoded for analysis. From the table 4.2 it is evident that distinctions between the qualitative and quantitative research approaches are situate in their methodology. In all, there is basically no superiority of one approach over the other. The nature of a particular research spells the most suitable research strategy to adopt and the resultant research method to apply.

	Quantitative Research	Qualitative Research
Assumptions	Social facts have an objective reality	Reality is socially constructed
	Primacy of method	Primacy of subject matter
	Variables can be identified and relationships measured	Variables are complex, interwoven, and difficult to measure
	Etic (outsider's point of view)	Emic (insider's point of view)
Purpose	Generalizability	Contextualization
	Prediction	Interpretation
	Causal explanations	Understanding actors' perspectives
Approach	Begins with hypotheses and theories	Ends with hypotheses and grounded theory
	Manipulation and control	Emergence and portrayal
	Uses formal instruments	Researcher as instrument
	Experimentation	Naturalistic
	Deductive	Inductive
	Component analysis	Searches for patterns
	Seeks consensus, the norm	Seeks pluralism, complexity
	Reduces data to numerical indices	Makes minor use of numerical indices
	Abstract language in write-up	Descriptive write-up
Researcher Role	Detachment and impartiality	Personal involvement and partiality
	Objective portrayal	Empathic understanding
General framework	Seek to confirm hypotheses about phenomena	Seek to explore phenomena
	Instruments use more rigid style of eliciting and categorising responses to questions	Instruments use more flexible, iterative style of eliciting and categorizing responses to questions
	Use highly structured methods such as questionnaires, surveys and structured observation	Use semi-structured methods such as in-depth interviews, focus groups and participant observation
Analytical objective	To quantify variation	To describe variation
	To predict casual relationships	To describe and explain relationships
	To describe characteristics of a population	To describe individual experiences and group norm
Question format	Closed – ended	Open – ended
Data format	Numerical (obtained by assigning numerical values to response)	Textual (obtained from audiotapes, videotapes and field notes)
Flexibility in study design	Study design is stable from beginning to end	Some aspects of the study are flexible (for example, the addition, exclusion or wording of particular interviews questions)
	Participant responses do not influence or determine how and which questions researchers ask next	Participant responses affect how and which questions researchers ask next
	Study design is subject to statistical assumptions and conditions	Study design is iterative, that is, data collection and research questions are adjusted according to what is learned

Table 4.2: Comprehensive distinctions between the quantitative and qualitative research approaches

Adapted from Siegle (2002) & Mack et al., (2005, p.3)

As regards the mixed method of research, as the name implies, this entails blending the elements of the quantitative and qualitative research approaches in order to define a suitable and distinct research design based on the identified philosophical assumptions and theoretical framework (Creswell, 2014). The appropriate mix of these components according to Johnson & Christensen (2014) heavily depends on the proposed research questions and the exact situational issues faced by the researcher. With an objective of collecting both qualitative and quantitative data, the mixed method approach seeks to neutralize the weakness of each data form by identifying a point of convergence generally known as triangulating data sources (Creswell, 2014). Thus, the main trust of this strategy is to provide a complete or unified understanding of the research task (Creswell, 2014 and Johnson & Christensen, 2014).

4.3.2 The Deductive, Inductive and "Abductive" research

In the opinion of Ventovuori (2007), the decision to choose a specific research approach is best informed by the selection of an appropriate research logic which will help the researcher understand the phenomena under examination. As noted by Saunders *et al.* (2009), the major research logics are the inductive and deductive research. Adoption of inductive reasoning suitably works when there is need to collect data to form themes or categories, identify patterns in a specific data or make generalizations such as statistical hypothesis emerging from samples to populations, or from literature, or even based on previous experience (Johnson & Christensen, 2014). Thus, the logic of confirmation is considered as inductive since no conclusive proof based on any empirical research has been arrived at. In contrast, deductive reasoning applies when observable consequences are deduced from the test of hypotheses through statistical analysis using empirical data (Johnson & Christensen, 2014). Further, as posited by Robson (2002), the deductive research which is the central research in natural sciences, entails the development of testable statements (based on existing theories) as hypothesis, testing of same in the real world, investigation of the outcomes(s) and where necessary, varying the theory consequent upon the findings. Accordingly, a very concise theoretical description of the difference between these concepts is offered by Marshall (1997, p.17; & 2014) as follows:

> *"When researchers first begin to open up any new line of enquiry there will be no useful theories available from which to deduce propositions for testing. Knowledge has to begin with collecting facts and then trying to find some order in them. This is known as induction. Deduction is the technique by which*

> *knowledge develops in more mature fields of enquiry. It involves a sort of logical leap. Going a stage further than the theory, data is then collected to test it".*

Although Saunders *et al*. (2003) earlier proposed that the inductive research approach provides more room for deeper explanation to a phenomenon, the above statement by Marshall (2014) tends to rather create a bridge between these two broad research strategies rather than deferring this position. This is seen in the statement that induction implies gathering and seeking some order in sourced facts, while deduction advances into developing these ordered facts into matured fields of enquiry. This therefore gives some idea of the integration potentials between the inductive and deductive research strategies. In line with this substance, Dubois and Gadde (2002) put forward a concept they called abductive logic or in other words, systematic combining. Their argument was that theories are not easily understood in the absence of empirical assessments; thus, it is more favourable to assess both old theories, while proposing new ones, as it is in very rare circumstances that research and knowledge development are found to be specifically inductive (i.e. data – specific) or deductive (i.e. theory – specific).

Referring back to the main research approaches, quantitative research approach centres on two key activities: testing of hypothesis and theory, it is considered as confirmatory scientific method of research; and granted that qualitative research approach focuses on developing new theories and hypothesis, it is conceded as explanatory (Johnson and Christensen, 2014). Yet several researchers advocate that for a complete understanding of any research, both the confirmatory and explanatory elements must be factored in (Dubois & Gadde, 2002; Johnson & Onwuegbuzie, 2004; Creswell, 2014).

Crystallizing these broad thoughts therefore provides the inference that qualitative data analysis takes an inductive approach because it principally seeks to discover new theories from very limited knowledge of a subject, and its investigation progresses from the specifics to the general themes; whereas, quantitative data analysis adopts a deductive strategy of testing existing objective theories and hypothesis (Creswell, 2014). Lastly, the mixed research method can be safely given the attribute of abductive research, in that, it combines the unique elements of both quantitative and qualitative methods in varying proportions for an optimal and unbiased research data analysis.

4.4 Research Strategies and Methods

Research strategy in the view of Saunders *et al.* (2009, p.600) is *"the general plan of how the researcher will go about answering the research questions"*. As suggested by Yin (2013, p.9), the choice of an appropriate research strategy is founded on three conditions: i) the type of research question presented by the researcher ii) the extent of control a researcher has over actual behavioural events, and iii) the degree of focus on contemporary as opposed to entirely historical events. Further, Yin (2013) also proposed that there are five categories of research methods: experiment, survey, archival analysis, history, and case study; and explained the application of these research methods based on the aforementioned selection of a suitable research strategy, as revealed in table 4.3. It is important to note from the table that case study which is the adopted method for this research is employed where questions such as *"how?"* and *"why?"* are to be given answers to.

Method	Form of Research Question	Requires Control of Behavioural Events?	Focuses on Contemporary Events?
Experiment	How, why?	yes	yes
Survey	Who, what, where, how many, how much?	no	yes
Archival Analysis	Who, what, where, how many, how much?	no	yes/no
History	How, why?	no	yes
Case Study	How, why?	no	yes

Table 4.3: Selection of appropriate research methods

Source: Yin, (2013, p.9)

Although in contrast, Blaxter *et al.* (2010), argues that research methods comprise: action research, discussions, interviews, observations, documents and questionnaires, an unbiased way of viewing these methods is to consider them as instruments designed for discrete research methodologies or strategies. This position is consistent with the definition of research methods by several authors as tools or techniques for carrying out a specific research (Bailey, 2008; Smyth and Morris, 2007; Fellows and Liu, 2009). In the barest sense of it, Bryman (2012) defined research methods as *"simply a technique for collecting data"* (**p.46**), whereas, research strategy is associated with *"a general orientation to the conduct of research"* (**p.35**) and classified the main types of research techniques to include the quantitative and qualitative research strategies as clearly revealed in table 4.4.

	Quantitative	Qualitative
Principal orientation to the role of theory in relation to research	Deductive; testing of theory	Inductive: generation of theory
Epistemological orientation	Natural science model, in particular, positivism	Interpritivism
Ontological orientation	Objectivism	Constructionism

Table 4.4: Core differences between major research strategies

Source: Bryman, (2012, p.36)

To this end, sequel to the preceding comprehensive description of research strategies and methods, it is evident that in view of the exclusively numerical nature of data associated with this research, its research strategy is quantitative. Accordingly, granted that specific industrial sub-sectors with historically water intensive processes have been chosen for in-depth cause and effect investigation, the case study research method is conceded as most suitable for this research; thus adopted. To this end, since the quantitative, qualitative and mixed research strategies or approaches have been clearly expounded in the preceding sections, the succeeding segments of this chapter will feature the meaning and application schemes of the case study research method.

4.4.1 The case study

As defined by Yin (2013, p.16) *"a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident."* In principle, the case study research *"is used to gain in-depth understanding replete with meaning for the subject, focusing on process rather than outcome, on discovery rather than confirmation"* (Burns 2000, p.460). This case could either be a process or a phenomenon, animate or inanimate, *"episode, process, community, society or any other unit of social life"* (Kumar, 1996, p.99); the principal aim being to create patterns that can be applied to comparable subjects without having to evaluate the entire subjects independently.

As proposed by Yin (2014, p.17) case studies focus on discrete technical phenomena; they depend on diverse sources of evidence and are easily identified where a phenomenon is not readily distinguishable from other social problems under investigation. This explains the *"probe component"* of the case study research method which is aimed at gaining a comprehensive understanding of a distinctive case. Thus, case study *"provides an opportunity for the intensive analysis of many specific details often overlooked by other methods"* (Kumar, 1996, p.99).

However, there seems to be an exclusion of the quantification aspect of cases in most definitions of case study as a research method. Highlighting this argument, Dul and Hak (2008, p.4) defined the case study research method as *"a study in which (a) one case (single case study) or a small number of cases (comparative case study) in their real life context are selected and (b) scores obtained from these case are analysed in a qualitative manner".* This definition lends support to the teeming descriptions of case study research as a qualitative research strategy (Creswell, 2014, p.4; Denzin & Lincoln 2011, p.250; Hatch 2002, p.31; Berg & Lune 2014, p.5); as listed by Creswell (2014, p.12). Qualitative research designs include: narrative research, phenomenology, grounded theory, ethnographies and Case studies; while Berg and Lune (2014, p.5) suggests seven methods of qualitative data collection methods namely: interviewing, focus groups, ethnography, sociometry, unobtrusive measures, historiography and case studies. In contrast, Collis and Hussey (2009) argue that case study is not qualitative – specific; their definition of case study is that it is "*a methodology that is used to explore a single phenomenon in a natural setting using a variety of methods to obtain in-depth knowledge*". Going further, Eisenhardt and Graebner (2007) further defended this proposition in their assertion that case studies can also be historical; whereas, Yin (2013) and Gerring (2007) concede that it is a research method that is applicable to both the quantitative and qualitative data, enabling the investigator *"to get a rich mix of the data for the study"* (Wedawatta, *et al.*, 2011). Explicitly described:

> *"While case studies can be very quantitative and can test theory, in education they are more likely to be qualitative. A case study design is employed to gain an in-depth understanding of the situation and meaning for those involved"* (Merriam 1998, p.19).

Consequently, the author additionally gave a clearer insight into the categorical application of the case study in the clear-cut assertion that *"a <u>qualitative case study</u> is an intensive, holistic description and analysis of a single instance, phenomenon, or social unit"* (Merriam 1988, p.xiv; 1998, p.xiii). This definition provides a classification for case study types in terms of qualitative and quantitative cased studies. Further confirming the neutrality of case study research, Burns (2000, p.460) considers that *"in a case study the focus of attention is on the case in its idiosyncratic complexity, not on the whole population of cases"*; whereas, Michael (1999) inferred that, case study research is actually eclectic: it does not follow any distinctive method(s) of data collection. This feature according to the author makes it a unique method of research enquiry. To this end, the standard of aiming to gain an in-depth understanding of a phenomenon should be the thrust of any case study research; this is applicable to both the qualitative and quantitative research approaches (Yin, 2013; Gerring, 2007; Wedatta *et al.*, 2011).

Of importance therefore is to understand how the case study method can be applied where the objective is to study how distinctive cases can be investigated relative to similar cases or phenomena. As proposed by Yin (2003), there are four kinds of case study designs, these include: the *"single case holistic design"*, *"single case embedded design"*, *"multiple case holistic design"* and *"multiple case embedded design"*. According to the author, the single case research (holistic or embedded) applies where a discrete or unique case or phenomenon is considered for rigorous investigations, or to test a specific existing theory; whereas, in the view of Saunders *et al.* (2009), the multi case is used by investigators to examine if the finding(s) of a distinctive case is replicate in other cases, thus creating the possibility of generalising these findings for the development of a robust theory.

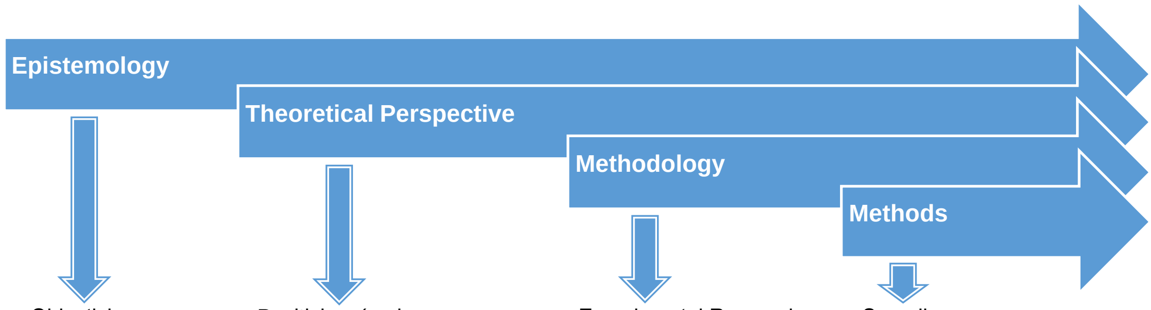
Hence, given the quantitative nature of data associated with this doctoral research and its focus on the industrial sector's water use, the need for precision of outcome within a *"boundary of study"* (industrial sector) underpins the decision to adopt a case study strategy for this assessment. Although, in specific terms, the research design for this study shall be the multi case with specific investigation into the embedded units. According to Yin (2003) this method is prioritized where a study intends to assess the casual relationship (in this setting, the hypothesis testing) and gives the investigator the means to make generalizations consequent on observation of replications or patterns among cases. This logic relocation strategy of the multi case design is in the opinion of Yin (2009) analogous to the multi experimental research approach, as each case is chosen to either (a) predict comparable results (consistent with the literal replication) or (b) predict contrasting results but with anticipated reasons (as in the theoretical replication). Hence, this method is based on the credence that the individual cases being investigated are typical cases of a certain kind, and with its intensive analysis, generalizations may be made that will be applicable to other cases of same types (Kumar 1996, p.99)

4.5 Research Design

Research designs are plans, procedures and decisions that range from major assumptions to detailed methods of data collection and analyses (Creswell, 2009). As closely defined by Frankfort-Nachmias and Nachmias (1996) research design is *"a logical model of proof that allows the researcher to draw inferences concerning causal relations among the variables under investigation".* Key factors to be taken into consideration in research designs include: the study purpose, sample types, the data collection and analysis methods, and the anticipated outcome of the research (Sekaran, 2003). More concisely, research design according to Bryman and Bell (2011, p.40) is *"a framework for the collection and analysis of data."* The choice of research design in the opinion of the author should *"reflect decisions about the priority being given to a range of dimensions of the research process"*; whereas, in the opinion of Creswell (2014, p.247) they are types of inquiry within qualitative, quantitative, and mixed method strategies that provide specific direction for procedures during a research study.

In the preceding sections of this report, several theoretical structure or broad theory-based explanations and philosophical perspectives have been scrupulously detailed; these have served as lens to guide the researcher in the choice of a suitable research methodology, approach, strategy and methods. As a comprehensive outline of these crucial parts of research in any area of research, table 4.5 is presented to explicitly direct the research design route. From the table, the epistemology of this research is Objectivism because this study is exclusively a quantitative research; hence, the apposite paradigm or perspective for this research is positivism.

Further, the research approach of this doctoral investigation is quantitative, this theoretically constitutes the research methodology of this study. Lastly, the adopted research method is case study; whereas, the strategies of the data collection include: documents, discussions, data collections through applications to UK environment regulators (EA, SEPA, NIEA), water undertakings and trade bodies.



- Objectivism
- Constructionism
- Subjectivism

  (& their variants)

- Positivism (and Post - Positivism)
- Interpretivism
  - Symbolic interactionism
  - Phenomenology
  - Hermeneutics
- Critical Inquiry
- Feminism
- Postmodernism

  etc.

- Experimental Research
- Survey Research
- Ethnography
- Phenomenological
- Research
- Grounded Theory
- Heuristic Inquiry
- Action Research
- Discourse Analysis
- Feminist standpoint research
- Qualitative Approach
- Quasi - Experimental
- Quantitative Approach
- Meta-Analysis

  etc.

- Sampling
- Measurement and Scaling
- Questionnaire
- Observation (Participant/Non-Participant)
- Interview
- Focus Group
- Case Study
- Life History
- Narrative
- Visual ethnographic method
- Statistical Analysis
- Data reduction
- Comparative Analysis
- Cognitive Mapping
- Interpretive methods
- Document Analysis
- Content Analysis
- Conversational Analysis

  etc.

Table 4.5: Relationship between epistemology, theoretical perspectives, methodology and research methods

Source: Crotty (2005, p.5)

Notable, in the inductive research, data are collated and analysed to identify patterns or seek substantive links between variables and ultimately develop new theories; whereas, deductive research entails using existing theory to develop working hypotheses that are aimed at deducing relationships between variables (Gary 2009, p.37). On this note, this research adopts a deductive approach in order to test the proposed hypothesis and established theories based on test of the research hypotheses, review of literature and observation of trends in UK industrial water use. Further, to thoroughly explicate the research design of this study, three crucial aspects are detailed in the succeeding part of this section this study; thus the research design will include the definition of the benchmarking scope, design of the conceptual model for the benchmarking exercise, development of a data inventory and methods of data analyses

4.5.1 Benchmarking scope definition

A clear understanding of what data is to be collected, benchmarking partners to be selected, how best to source requisite data and what results or targets are to be achieved within a given period of time, defines the scope of the benchmarking process.

Going by the 2007 Standard Industrial Classification, the UK industrial sector is so vast that a single study may not be enough to cover its teeming economic activities. Thus, major water intensive sectors shall be selected based on water use antecedents; this will ultimately help in framing the scope of this study in terms of the subsectors to be case studied.

From a recent study conducted by European Commission (2009), Europe as a whole uses so much as 34,194Hm^3 of water annually for its industrial purposes; although, industrial activities with very large water consumptions vary from one member state to the other. Going further, in a bid to identify which industrial sectors consume significant quantity of the water resource in different member states, the study ranked the highest water consuming industries from 1 – 5 (5 being most consuming, … 1 for least consuming) relative to their share of water consumption amongst each member state as depicted in table 4.6.

Member States	Chemicals	Thermal power plant electricity generation	Food and beverage	Fuel Installations	Metals production & transformation	Pulp, paper & cardboard	Waste & residue mgt.	Textiles
United Kingdom	4	5	2		3	1		
Estonia	3		4	1	5		2	
France	5		1	4	3	2		
Portugal	2		4		3	5		1
Netherlands	2		5	3		4		
Total	**16**	**5**	**16**	**8**	**14**	**12**	**2**	**1**

Table 4.6: Ranking of industries according to national industrial water use

Data source: ONS (2001), Bouvet et al. (2007), Silva et al, (2002) and Netherlands Environmental Assessment Agency (2005) cited in European Commission (2009)

Focusing on United Kingdom, thermal power plant electricity generation is the most water intensive industrial process, closely followed by Chemicals, then metals production and transformation, and lastly pulp, paper and cardboard. Accordingly, a comprehensive investigation on water intensive processes in UK was conducted by DEFRA (2007, cited in The Institute of Grocery Distribution, 2007). The report of this assessment presented a generalized estimate of average water use by major industrial sectors annually (see Table 4.7). It can be seen from the table that Food and drink sector alone uses the available fresh water in the UK to the tune of 307 million m^3/year. This ranks Food and drink sector as highest water user in the industrial arena, closely followed by the chemical manufacture sector.

Sector	Annual water use – millions m^3 (tonnes)
Food and drink processing	307
Chemicals	273
Electronics	241
Paper and board	155
Plastic and rubber	83
Textiles and leather	63

Table 4.7: UK annual water use by major industrial sectors

Adapted from: DEFRA (2007)

It is thus imperative to note that these are mainly consumptive water uses of which 20 – 30% of the water used is retained in the products (DEFRA, 2007). These large consumptive water processes constitute areas of highest water savings. To this end, this study shall focus on five water critical industrial subsectors *inter alia*: Thermo-electric power generation, Chemicals, Metals production and transformation, food and beverage, and pulp and paper. The Electronics sector may eventually be assessed; however, this remains a function of water use data availability for the sector. Suffice it then that the emphasis of this study will be on actual water use not embedded.

4.5.2 Development of the conceptual framework

Based on this study, review of literature served to identify the most current research, major concepts and theories associated with academic research, and helped to uncover what methods other researchers used in their research relative to the current study. Although, just comparing one's research to others is considered insufficient for the comprehensive study requirement of any doctoral research; thus, adding the requisite academic rigour to this work entailed the development of a conceptual framework from the established research theories. This structure will help to holistically reflect the research design, and especially illustratively reveal the research methodology – information collection methods, data analysis and its corresponding results' interpretations. According to Miles *et al*. (2014, pp. 24, 25),

> *"The conceptual framework, then, is your first analytic display. It is a visual representation of your main conceptual ideas about a study and how they interact and interplay with each other" ... "[c]onceptual frameworks are best*

done graphically rather than in text. Having to get the entire framework on a single page obliges you to specify the bins that hold the discrete phenomena, map likely interrelationships, divide variables that are conceptually or functionally distinct, and work with all of the information at once"

The choice of a suitable conceptual framework is therefore informed by the scope and anticipated outcome of the research. Figure 4.2 details each activity of the benchmarking study. This serves as a roadmap to guide the researcher towards the ultimate aim of the research and as a gauge for monitoring the progress at each stage.

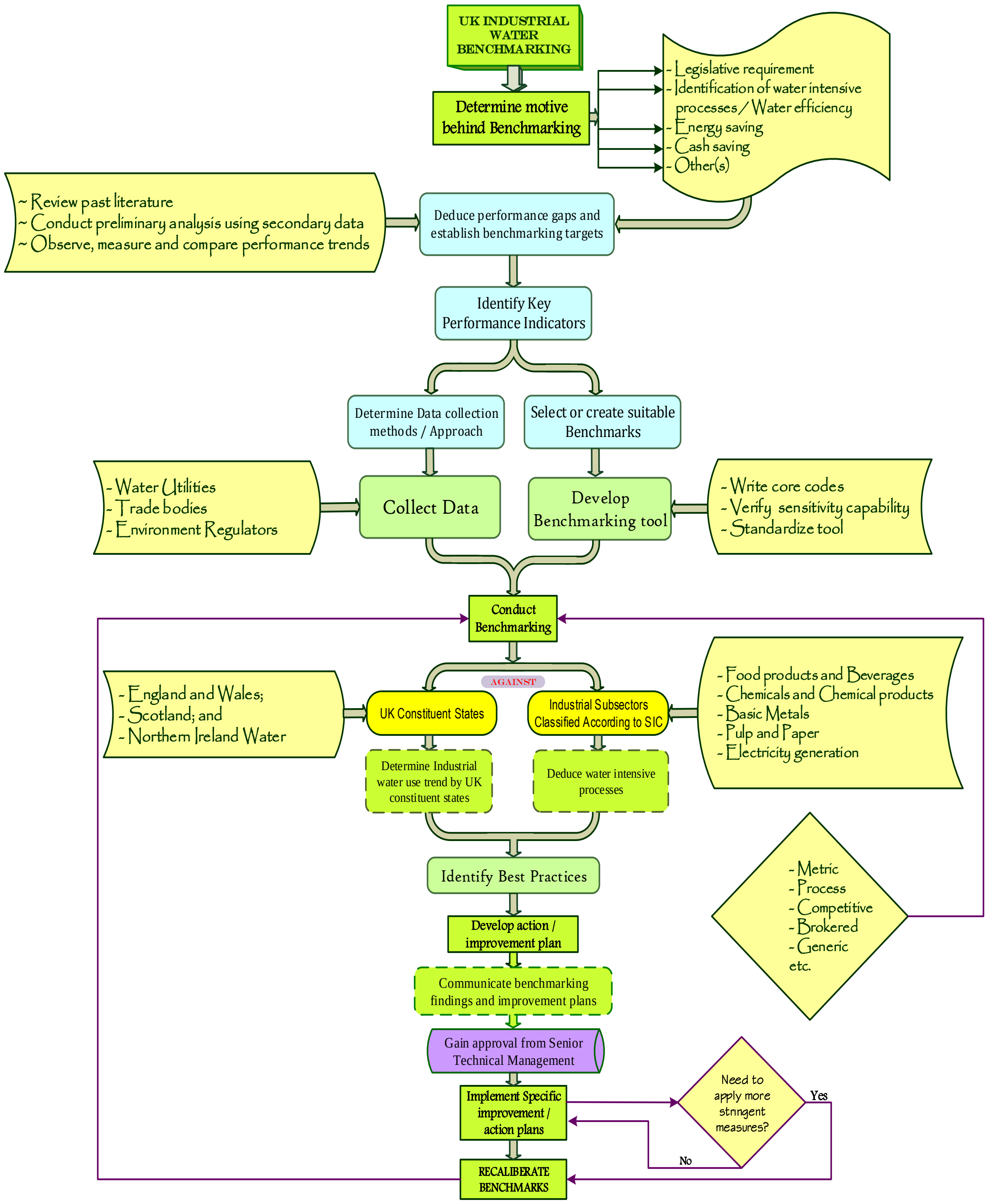


Figure 4.2: Conceptual framework for the UK industrial water benchmarking

Furthermore, the conceptual framework serves to link the identification of theories with the data collection, thus enabling the test of theoretical propositions / hypothesis. It also helps in data quantification and explanation of inherent casual relationships that exist in a body of data (Malhotra, 2002). As suggested by Miles and Huberman (1994), data collection is best achieved with the conceptual framework which is informed by the research questions and objectives.

4.5.3 Data inventory development

Every benchmarking effort involves the development of a profile inventory of the utility to be benchmarked; this includes the *"basic demographic, geographic, governance and financial information"* (Paralez, 1999). Accordingly, assessment of any previous improvement attempt will help in suggesting areas of greatest concern. The frequency of data storage must be established. These preliminary exercises shall frame the potential outcome in terms of the accessible data – its source(s), quality, usability and resource (time and financial) implications of its collection. It is noteworthy that in sourcing requisite data, it is best to indicate the data status, that is, if datasets are estimated or actual or collected using a rough order of magnitude (rom). This according to Peralez (1999) helps in establishing *"a context for the quality of the data."*

4.5.4 Data availability, accessibility and usability

Access to accurate data or information on performance of water utilities is the first step in any water benchmarking exercise. This helps in identifying the exact performance trend and problems confronting a benchmarked utility. The availability and quality of required data is often reflected on the infrastructural status of an organisation. Data measurement and collection processes can either be manual, automated or automatic. Although, there is the *"human – element"* in every collection method – as meters must be read and computer metrics must be interpreted, but the sole reliance on the manual approach for measurement and collection could lead to false data collection. The automated and automatic systems of data handling give more accurate results; however, it requires additional capital investment in order to get the requisite infrastructure in place.

4.5.5 Data collection and collation

Data or information collection is an integral step in every benchmarking process and conducting comparisons require an extensive measure of data that are usually difficult to collect (Berg, 2010). Whereas, either a system or part of a system's performance can be benchmarked, specifying specific areas of interest shall help in defining the kind of data to be collected.

The most time consuming part of any benchmarking process is the collection of technical information on how water is used on a site. This has been attributed to the absence of water meters and consideration of water as a free and infinite resource.

After inspecting the collected data to ascertain its accuracy, the researcher is to collate or sort the raw data into groups. These datasets will be in relation to the goal (aim and objectives) of the benchmarking exercise, as well as the intended statistical method to analyse the data.

4.6 Data Analysis

This section presents a comprehensive description of how data collected for this research were analysed. Whereas, different statistical methods were adopted, their corresponding assumptions are also outlined in this segment. This section therefore provides the rationale behind the choice of one statistical method over the other. Further, it is appropriate to state that since the data collected for this study are basically quantitative (interval and ratio scales) and time series, two main parametric statistical methods are adopted for the statistical analyses, they include the Regression analysis and ANOVA; these shall be detailed in the succeeding sections. However, for both inferential tests, an indispensable requirement is that data used for the analysis are sampled from a population. Thus the sampling methods used for the statistical procedures are explained in the subsequent section.

4.6.1 Data sampling

A sample as defined by Fink (2003, p.1) *"is a proportion or subset of a larger group called a population ... A good sample is a miniature version of the population of which it is a part – just like it, only smaller"*. Basically, there are two sampling methods or techniques: the probability or random sampling technique and the non-probability sampling. As remarked by Saunders *et al*. (2009), probability sampling comprises of all sampling forms in which data to be used for any statistical analysis or test is selected pursuant to some founded laws of chance in such manner that every data in the population stands an *"equal"* chance of being selected. Probability techniques include: stratified random sampling, cluster sampling, and systematic sampling. In contrast, non-probability sampling is a non-random method; it entails the exclusion of chance in selection of data for statistical analysis. Typical examples of non-probability sampling techniques include purposive or judgemental sampling, convenience sampling and quota sampling (Udofia, 2011).

For this research, the stratified random sampling is adopted; this entails dividing the population into strata in order to ensure that each stratum is represented in the sample. In data sampling, two key aspects are needed for its full implementation: the sample frame and the sample size.

i. *The sample frame*

This is considered as a precondition of any data sampling exercise and involves condensing the entire elements of a population into a data list. For this study, data collected came from the secondary sources. Three major groups were contacted, they are: the four UK Environmental regulators, major UK trade bodies and 27 UK Water companies. These are outlined below as the sampling frame for this study.

A ENVIRONMENTAL REGULATORS
1 Environment Agency
3 NIEA
2 Environment Agency Wales
4 SEPA

B TRADE BODIES
1 Food & Drink Federation
2 WRAP
3 Water UK
4 Waterwise
5 Envirowise Ltd
6 Chemical and pharmaceutical industry
7 Dairy UK
8 The Scotch Whisky Association
9 Beverage Industry Environmental Roundtable
11 Federation House Commitment
12 Resource Efficient Scotland
13 Office for National Statistics
14 DEFRA

C WATER COMPANIES
1 Affinity Water
2 Albion Water
3 Anglian water
4 Bristol Water Plc
5 Cambridge Water
6 Cholderton & District Water
7 Dee Valley
8 Dwr Cymru (Welsh Water)
9 Independent Water Networks
10 Northern Ireland Water
11 Northumbrian Water (including Essex & Suffolk)
12 Peel Water Networks
13 Portsmouth Water
14 Scottish Water
15 Sembcorp Bournemouth Water Ltd
16 Severn Trent Water
17 South East Water

18	South Staffs Water
19	South West Water
20	Southern Water
21	SSE Water
22	Sutton and East Surrey Water
23	Thames Water
24	United Utilities Water
25	Veolia Water Projects
26	Wessex Water
27	Yorkshire Water

Of the data collection contacts made to the above bodies, 82.3% of these organisations responded and provided their data to the researcher. For the remaining 27.7% of organisations where data were not successfully collected, Water UK, Waterwise, Federation House Commitment and Envirowise referred the researcher to the WRAP who at the time of this report had collected data covering the manufacturing and electricity generation sectors of UK industry. It was not possible to collect data from Beverage Industry Environmental Roundtable; however, data collected from the Environment Agency covered this sector favourably. In a nutshell, there was a significant response from the contacted bodies. Appendix C reveals the instruments used for collected the requisite data; these include the Application letter for research data collection and the Approval to source data for PhD research.

ii. The sample size

The sample size is one key component of data analysis that helps enhance the level of confidence in the results of any statistical assessment. As noted by Saunders *et al.* (2009), the choice of a sample size is informed by: (A) the level of certainty that the characteristics of the data collected will represent the characteristics of the total population; (B) the margin of error that can be tolerated; (C) the type of analysis to be used, and (D) the size of the population.

Although sample sizes are read off from sample size selection tables, this study adopts the formula developed by Yamane (1967) because it incorporates the confidence level, and the precision level which should take care of any possible sample error. The formula is $n = N / (1 + N (e)^2)$; where n = sample size, N = Population size, e = level of precision = 0.05 at 95% confidence level.

4.6.2 Regression analysis and correlation

Regression as defined by Khan (2013, p.345), entails *"building a mathematical model which describes the relationship between one or more predictors and a single response variable"*; whereas, correlation, verifies whether two statistical variables have a linear relationship, with the correlation coefficient (r) helping to reveal the strength of the relationship. The range of r is delimited between -1 to +1; where -1 connotes a negative relationship, +1, a perfect (positive) relationship and 0 meaning a situation of no relationship between the two variables.

Before any statistical test is performed, it is pertinent to confirm that conditions for the test are met. As emphasized by Osborne and Waters (2002, p.1), regression assumes that variables are normally distributed (not highly skewed, or with large outliers or kurtotic); however, test of normality is actually not about the X or Y variables individually, or as most often seen, to do with the Y or dependent variable alone. It is the normality of the residuals (errors or deviation) or Y with respect to X. So regression basically assumes that the residuals are normally distributed. This assumption will be checked before any regression analysis is conducted.

4.6.3 ANOVA and its assumptions / conditions of use

Known as analysis of variance or ANOVA and developed by Sir Ronald Fisher (a British statistician), the test constitutes one of the inferential methods employed to investigate whether or not there is a statistical difference between at least two means in a dataset. The computed test statistic for the ANOVA is based on the F distribution; the F being named after Fisher (Sheskin 2003, p.526). But before any analysis is conducted using the ANOVA, there is need to understand the conditions governing its application. The two key assumptions of ANOVA include the assumption of normality of residuals and homogeneity of variance or homoscedasticity or test of equal variances (Proulx, 2011, p.334; Ellison, et al. 2009, p.143; TBA 2008, p.14).

Homoscedasticity applies where the variance of errors in a distribution is the same across all levels of the independent variable. In practice, test of normality could be easily carried out by visually inspecting data plots, skewness and kurtosis; while by visually examining a plot of the standardized residuals (the errors) against the standardized predicted values, homoscedastic or heteroscedastic can be inferred. These processes are generally known as eye-balling. However, most statistical software programs run these tests with remarkable levels of precision, and provide results from which it can be confirmed that these two assumptions are met or violated. In Minitab, the assumption of normality of data residuals is tested by storing the data residuals (normally standardized) in a separate column and conducting normality test on the data residuals; whereas, for the assumption of homogeneity of variance test, an F-test, a Bartlett's or Levene's test is conducted. These compare variances of the considered samples. The F-test is performed where there are only three factor levels or groups; while in the case of three or more factors levels or groups, the Bartlett's test is conducted (Minitab, 2015b). Accordingly, when data is not normally distributed, the Levene's test is used (Bryman and Cramer, 1996); whereas, for one and two factor level(s), the 1 variance and 2 variance options under the *"Basic Statistics"* of the Minitab is used to perform the test of equality of variance(s) respectively.

Further, it is pertinent to state that where a distribution fails the normality test, the first remedial measure to be taken is to transform the data. In Minitab, this can be achieved using either the Box-Cox or the Johnson transformation method. The Box-Cox method has the capability of choosing the most optimal λ value; although, it cannot transform negative values. This is where the Johnson transformation thrives, as it accepts and transforms non-normal negative values.

Accordingly, in the event of failure of test of equal variances, the Welch's ANOVA is an elegant solution because it is a form of one-way ANOVA that does not assume equal variances (Frost, 2014). When compared with the normal one-way ANOVA, Frost (2014) discovered that *"the traditional one-way ANOVA ranges from 0.02 to 0.22, while the Welch's ANOVA has a much smaller range, from 0.046 to 0.054"*; this added advantage of the Welch's test makes it suitable for data with unequal variances.

4.6.4 The post hoc or a posteriori test

It is pertinent to state that the ANOVA test (traditional or Welch's) is actually not the last test to be conducted in order to determine how statistically significant investigated variables are. The ANOVA which involves carrying out an ANOVA F-test only gives the indication that *"at least ONE of the pairs is significant."* Thus, to find out how many of the pairs have statistical differences, we conduct a Post Hoc or a posteriori test. For this exercise, the Tukey pairwise comparison is used, given its robustness and adaptability to variability of datasets. This test looks at differences between pairs of samples. The Minitab output for this test is a table and a plot. The table shows pairs that share or do not share alphabets, from where an inference of statistical difference can be drawn. Accordingly, the plot shows mean intervals of each compared pair; the aim being to identify confidence intervals that do or do not overlap the zero difference. If the confidence range is to one side of the zero level (i.e., do not overlap the zero point), we are X% (normally 95%) confident that there is a real difference between sample A and B of a particular pair. If the confidence level overlaps the zero point, then it is impossible to be confident that there is any real difference between samples A and B.

To this end, both assumption of normality of data residuals' and homogeneity of variance shall be discretely tested before any ANOVA is conducted in order to ensure validity of the results and eliminate any possible bias; whereas, a post hoc test will be conducted for each of the ANOVA procedures, in order to ensure that the exact pairs with statistically significant means are identified.

Chapter Five

5.0 Introduction

The prime aim of this chapter is to put the outlined principles of benchmarking into a practical perspective. In this section, the rationale behind the choice of the Visual Basic for Applications (VBA) as the appropriate programming language for the software development is presented, the Software Development Life Cycle (SDLC) is explained and key utilities of the *i*-Water Benchmarking Tool are detailed.

Accordingly, with the successful progression of the software development from its development cycle, through discrete testing stages, to the release candidate and maintenance, the *"Tool"* is eventually used for benchmarking analyses across selected industrial sectors. Whereas, separate statistical analysis software (Minitab) will be used for the statistical data analyses, the *i*-Water Benchmarking Tool is adopted for the benchmarking performance assessment; this will serve as a complementary platform for analysing the *"applicable"* research data, and deducing the performance of various industrial sectors in terms of their rates of water use.

5.1 Overview of Software/Tool Development

5.1.1 Selection of an appropriate High Level Language for developing the Benchmarking Tool

Design of the standalone software program required identification of the most suitable computer High Level Language (HLL) and an in-depth knowledge of its programming syntax. In selecting the most appropriate HLL, several benchmarking tools were assessed with the aim of identifying what influences the decision to use a particular HLL over others. Some of the benchmarking software programs evaluated are revealed in table 5.1 below.

Benchmarking Tool	Functions / Capabilities
Water Research Foundation - Effective Utility Management Benchmarking Tool	Process benchmarking specific: Compares effective utility management attributes such as customer satisfaction, product quality, financial viability water resource adequacy, etc. Although the tool does not conduct metric benchmarking.
American Water Works Association - Utility Benchmarking Survey	Benchmarks customer, business, water and wastewater operations and organizational development. Thus, the tool is specifically for process benchmarking.
AWWA Water Loss Control Committee (WLCC) - Free water audit software v4.2	Mainly aimed at enhancing accountability in water supply through the control of water loss during supplies.
IBNET - The International Benchmarking Network for Water and Sanitation Utilities tool.	Enables benchmarking of processes among organisations and provides requisite indicators for performance comparison.
The World Business Council for Sustainable Development Global Water Tool 2012; and	Focused on identifying water scarce areas and risks associated with further water intensive practices in such areas.
BEST WINERY version II for energy and water savings.	Assesses the water and energy use and costs in wine production. Thus conducts both metric and process benchmarking of water and energy use associated with the winery only.

Table 5.1: Major available water benchmarking tools and their capabilities

After closely examining these software programs, it was discovered (as revealed in the table 5.1) that none of these tools is designed to benchmark water use across a range of industrial divisions; accordingly, the tools do not produce graphical results showing where benchmarked organisations are ranked relative to other comparable organisations and industry best practice or standards. These limitations of the above tools informed the need to develop a tool that will include these capabilities and other considered relevant functionalities.

However, one thing is common about these tools, they were all developed using the Microsoft Visual Basic for Applications (VBA) computer language. This revealed the need to understand why VBA is chosen by these globally recognised water management institutions. Results of this investigation revealed that VBA is considered to be very stable (insignificant application runtime hitches), compatibility with all Office suites, and does not require the installation of a separate software to perform its heavy data analysis. However, it is not suitable for web platform developments as it is a closed source HLL. More so, given that most water companies / end users store their numeric data in eXceLSheets (.XLS) or Comma Separated Values (CSV), and Visual Basic is currently the core HLL for all Microsoft programmes, it is easier to paste sheets of water use data into the VBA operated excel-based tool. It is then a straightforward task to prompt VBA to sieve, analyse and benchmark same, *in lieu* of the rigorous requirement of single unit data input that is consistent with most non-VBA benchmarking tools.

On this note, the VBA was adopted for design of the benchmarking software; this involved the study of core codes for writing the program. Learning the HLL necessitated trainings, collaboration with School of the Built Environment IT staff and students from the Maths and computing department. Also, discrete application platforms were created within the tool to enable its application for different benchmarking purposes based on the chosen KPI – water use/unit product or process (relative); total water use (absolute); cleaning water; cooling water; etc. (WRAP, 2013a). This was achieved through writing several pages of core codes in modules, forms and sheets, and running of these to ensure that they are syntactically scripted.

5.1.2 The Visual Basic for Applications development platform

Visual Basic for Applications (VBA) is a comprehensive object-oriented programming (OOP) language used for writing structured computer codes that can be run in office suites to execute simple to very complex tasks. The advent of VBA followed the evolution of Excel 5.0, upon which the older programming language, Visual Basic (VB) was replaced. Suffice it that VB earlier supplanted the text-based (spreadsheet) macros (Shepherd, 2004). According to Microsoft (2009), though the Excel program is an extremely powerful tool for transforming, presenting and analysing data using its rich set of features provided in the User Interface (UI), there are greater operations the software UI capabilities cannot address. Thus, in addition to the complementary support of the standard excel tool, the VBA is developed to extend such operations in order to suit user – specific tasks. This ability of the excel VBA programming language, according to professional programmers, accords it the credence of being very intuitive and robust (Shepherd 2004, p.4; Walkenbach 2013, p.15).

Rather known as *"program"* in other development platforms, codes written in the Visual Basic Editor (the VBA programming environment) are called Macros (derived from the Greek word *Makros*, meaning large) or procedures or subroutines (Walkenbach, 2013). By default, Excel disables Macros to keep users as safe as possible; this is because some developers explore the powerful functionality of the VBA for sinister reasons. Though, it is recommended that only Macros in files from trusted sources should be enabled, yet, greater danger lies in running codes that are unfamiliar to users than in enabling Macros (which is a pre-requisite for executing VBA codes). Accordingly, even as VBA proves to be extremely useful for user-defined tasks rather than default Excel UI functions, it is a closed – source software development platform, meaning that codes written in VBA editor can only be used in Microsoft suites. This is technically considered as a downside to the VBA capabilities given that programming in recent years is inclined towards making development tools open – source, with knowledge sharing, integration and robustness of developed tools at the heart of this objective.

By the same token, there is the question of compatibility in the use of the VBA platform in Office suites of different versions. As pointed out by Walkenbach (2013), persons using older versions may not fully explore the advantages of features added to newer versions; however, Microsoft realising this problem, developed an Office Compatibility Pack (which is free), in other to enable users of Excel XP and Excel 2003 open and save workbooks in newer file formats, without necessarily transferring the new features to the older versions (Walkenback, 2013). But there are both merits and demerits of using VBA for software development. According to Walkenbach (2013), while VBA provides user-defined capabilities and has the capacity to perform intensive and very time-consuming operations within a shorter timeframe, it requires the installation of office suites to execute its codes and perform these operations. This on the other hand constitutes an advantage because most computers already have Office installed on them, which means that they do not need to undertake a separate software installation in order to use Tools developed using the VBA HLL.

5.1.3 Program development life cycle

Software development life cycle (SDLC) model according to Saleh (2009, p. 24) *"defines the framework under which a software product is going to be developed."* As pointed out by Puntambekar (2007), the SDLC is a sequential process of organizing, planning and scheduling software projects; the aim being to develop software in accordance with appropriate regulatory standards, and requirements of an organization, within a defined time. Though Khan & Khan (2014, p.1) considers SDLC as *"a structure imposed on the development of a software product"*, it is best viewed as a model which provides stakeholders with a clear understanding of the progress status of the software project from the planning phase to the deployment and use of the software (Jain & Jain, 2011). These definitions however lean towards the description of software product management. As put by Ebert (2014, p.17), *"product management is the management of a product, including solutions and services, over its life cycle with the objective of generating the biggest possible value to the business"*. Thus, Software Life Cycle Development can be said to be analogous to Software Product Management.

As revealed in several researches, numerous authors have proposed different life cycle models for software developments. Amina (2011) proposed 5 - stage cycle – *"pre-alpha, alpha, beta, release candidate, and the general availability release"*; whereas, Atwood (2008) suggested a similar set of 5 - phase cycle: Pre Alpha, Alpha Stages, Beta Stage, Release Candidate (aka gamma or delta). Accordingly, Saleh (2009) presented a 6 - phase SDLC model as follows: Requirement analysis, Design, Implementation, Testing and integration, and operation and maintenance. Lastly a shorter but detailed 3 - cycle model was offered by Langer (2012) to include: Development, Testing and Production. However, a close look at these propositions by different authors reveals some overlaps in the SDLC phases, even with the terminology dissimilarities.

i. Development cycle

The development cycle, as suggested by Langer (2012) encapsulates four major phases, including: Feasibility, Analysis, Design and the Actual coding. According to the author, feasibility normally involves budget or forecast; it involves carrying out a Return-On-Investment assessment which entails mathematical evaluations to determine if the project will in the long or short run provide requisite financial returns to the business. In other words, this process helps to determine if the software project makes business sense.

Once the financial feasibility is relatively ascertained, the next stage is to confirm other technical requirements such as how and where to get the right expertise for the software project; and if the software will be developed in-house, partnered or outsourced. This stage is often not as detailed as the analysis phase which involves employing specialist services for a thorough software development investigation. Whereas, there are several SDLC models, a very common and widely adopted type is the waterfall model. Figure 5.1 shows the principal activities of the waterfall model; these activities are subsumed under two major headings: the development and post-development phases.

⌛ *Analysis phase*

The analysis stage requires that the analyst creates detailed logical requirements that summarize all the needs for the software project, ensuring that the possibility of going back to sponsors for any support (financial or technical) is at least optimally minimised or even eliminated (Langer, 2012). According to Saleh (2009, p.26) key deliverables of the analysis phase include *"the software requirements specifications document, the acceptance test plan document, and the scope and vision document"*; these documents should serve as a guide for the entire software development activities. As opined by Saleh (2009), this phase captures the software project constraints, user needs, risks, quality requirements, assumptions, development context and functionalities. It is considered that most severe software errors are those not fixed during the analysis phase, as such, deliverables of this stage must be carefully revised and tested (verified) for consistency, correctness and completeness, among other crucial quality requirements (Saleh 2009, p.26).

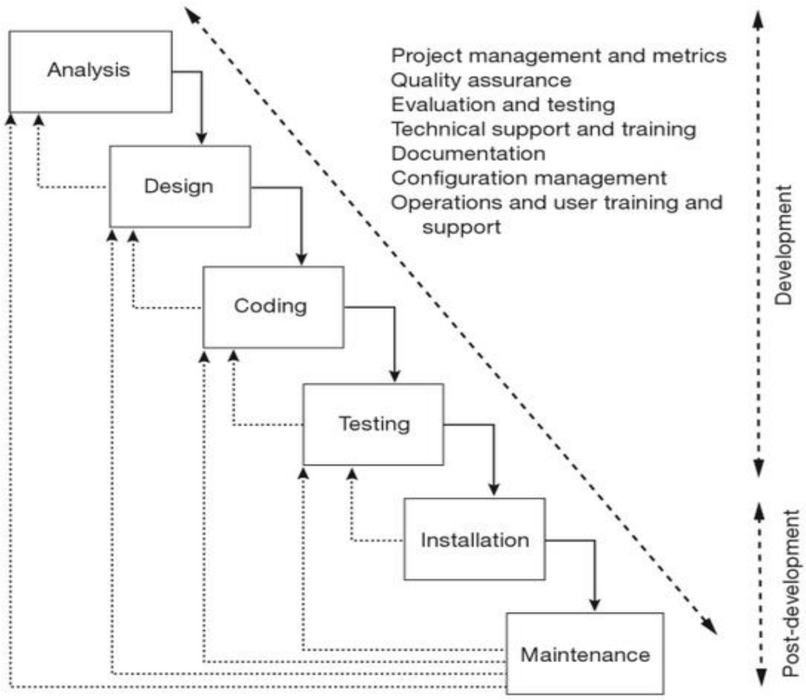


Figure 5.1: Waterfall model phases and its milestone activities

*Source: Saleh (2006, **p.26**)*

⌛ *Design Phase*

Consequent on the complete review and ratification of the deliverables by the associated stakeholders, the design phase follows. As recommended by Saleh (2009 p.26), *"the design activities include high-level architectural, database, interface, and detailed designs"*; whereas, *"the main deliverables of the design phase comprises of the* *high-level software design and detailed design documents."* According to Langer (2012, p.8), a greater aim of the design phase is to achieve an appealing and well-structured user interface, not on the engineering and mathematical aspect.

The Design phase which is less mathematical but more of creative, entails selecting the programming language that best suits the software development. It also includes deciding how the user interface should look like, etc. (Langer, 2012).

⌛ *Implementation or actual coding Phase*

Once the graphical user interface is completed, Selah (2006) suggests that the implementation phase follows. This implementation phase is also known as the actual coding phase (Langer 2012). Before discussing the coding aspect of any SDLC, it is important to understand what software technically means. According to Langer (2012, p.8), *"software is the physical abstraction that allows us to talk with the hardware machine"*; thus, coding is that way of developing a *"structured"* language that enables the *"communication or interaction"* with the real machine. This stage heavily depends on the developer's or team's expertise in software engineering.

⌛ *Software product quality assessment*

Proper coding entails writing a computer language in conformity with certain regulatory standard(s), in order to develop a software which meets a specific *"quality"*. Although, quality as a term is highly contextualized, a standard definition of quality is: (a) *"the degree to which a system, component, or a process meets specified requirements"*; and (b) *"the degree to which a system, component, or process meets customer or user needs or expectations"* (IEEE Std. 610-12-1990, cited in Lee, 2008); or as defined by the ISO/IEC 9126 derived from the ISO 8402 (which is the Quality vocabulary), quality is *"the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs"*.

There is therefore the necessity to relate statutory software quality to the development of a software within existing guiding rules or standards. There are many standards, but few apply to software quality; the list below as outlined by Lee (2008), constitute major standards associated with software quality:

ISO/IEC 9126-1, Software Engineering – Product quality – Part 1: Quality Model
ISO/IEC TR 9126-2, Software Engineering – Product quality – Part 2: External metrics
ISO/IEC TR 9126-3, Software Engineering – Product quality – Part 3: Internal metrics

ISO/IEC TR 9126-4, Software Engineering – Product quality – Part 4: Quality in use metrics

Some key components of the part 1 of the software engineering standards (Product quality) are succinctly captured in the model below (figure 5.2). The quality model gives a detailed and concise illustrative representation of the quality criteria requirements for software development. As defined by Azuma (2004, p.4), *"quality model is the set of characteristics and the relationships between them which provide the basis for specifying quality requirements and evaluating quality."*

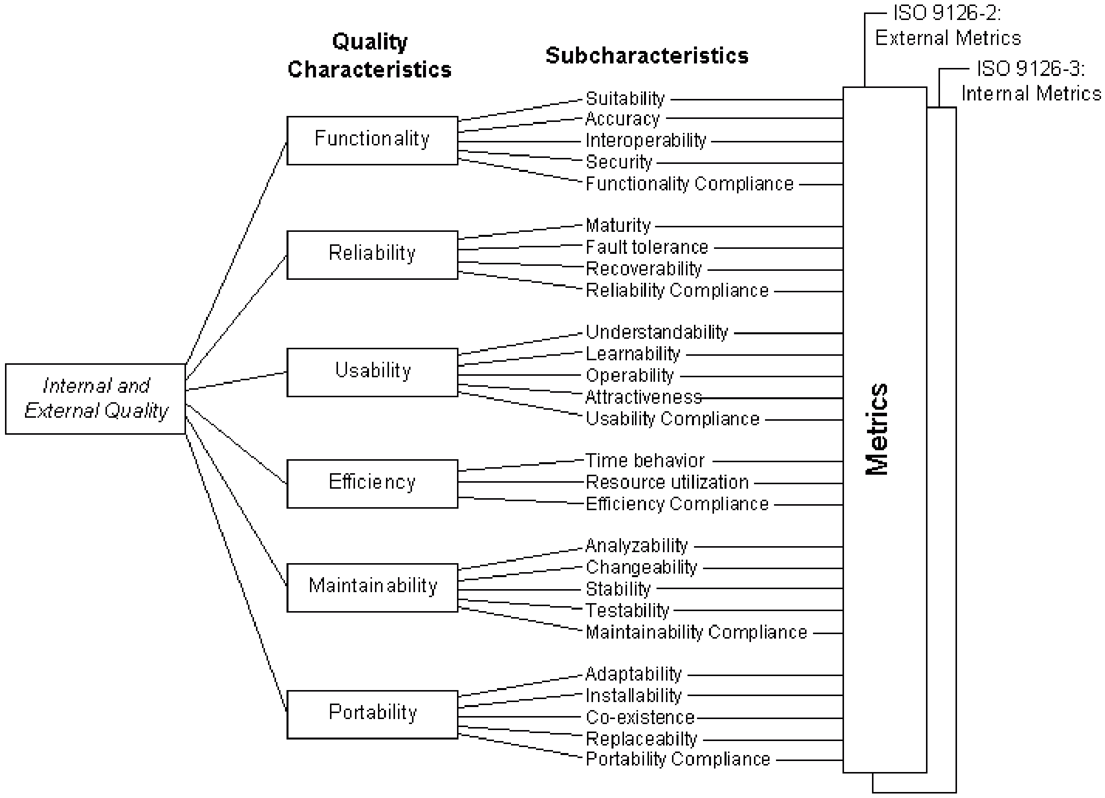


Figure 5.2: The ISO/IEC 9126-1 Internal/External Quality Model

Source: International Organization for Standardization. (ISO/IEC 9126-1) (2001, cited in SL Technologies, 2012)

The International Organization for Standardization (1994) (*ISO Standard 8402*) provided a standard definition of software quality model as *"artefacts used for defining the quality factors of a single software product of any nature (e.g., a custom-made application, a commercial off-the-shelf component or a web service) or a software domain (e.g., ERP systems or document management tools)"* (ISO, 1994, cited in Botella *et al.* 2004, p. 1)

It can be seen from Table 5.2 that ISO/IEC 9126-1 classified the software quality characteristics into six. Each *"characteristic"* in the model denotes *"the capability of the* *software product to achieve acceptable levels of risk of harm to people, business, software, property or the environment in a specified Context-Of-Use"* (ISO, 2001 - ISO/IEC 9126-1). Accordingly, as contained in the document (ISO/IEC 9126-1), internal quality is *"the totality of characteristics of the software product from an internal view. Internal quality is measured and evaluated against the internal quality requirements"*. Thus, the internal attributes denote those that can be measured during the development process; whereas, the external attributes can be measured during the testing phase. This position is consistent with the definition by ISO/IEC 9126-1 (ISO, 2001) that:

> *"External Quality is the totality of characteristics of the software product from an external view. It is the quality when the software is executed, which is typically measured and evaluated while testing in a simulated environment with simulated data using external metrics"* (ISO, 2001 - ISO/IEC 9126-1).

For a clearer understanding of the meaning of the quality characteristics contained in the model (figure 5.2), ISO/IEC FCD 9126-1 detailed the description of each attribute as revealed in table 5.2.

Quality Characteristics	**Definitions**
Functionality:	The capability of the software to provide functions which meet stated and implied needs when the software is used under specified conditions.
Reliability:	The capability of the software to maintain its level of performance when used under specified conditions.
Usability:	The capability of the software to be understood, learned, used and liked by the user, when used under specified conditions.
Efficiency:	The capability of the software to provide the required performance, relative to the amount of resources used, under stated conditions.
Maintainability:	The capability of the software to be modified. Modifications may include corrections, improvements or adaptation of the software to changes in environment, and in requirements and functional specifications.
Portability:	The capability of software to be transferred from one environment to another.

Table 5.2: ISO/IEC FCD 9126-1 definitions

Source: International Organization for Standardization. (ISO/IEC 9126-1) (2001, cited in Bevan 1999, p.5)

Suffice it that in 2004, a division of the software engineering subcommittee seven (SC7) known as the ISO Working Group Six (WG6) made proposals that included the introduction of a new concept called the *"quality measures"* – see table 5.3 (Abran, *et al.,* 2005, p.5). This scheme helped delineate the quality groups into quality measures. The internal quality metrics / measures serve as checkboxes for the quality groups. The aim being to ensure that a uniform standard of software quality applies to all software programs developed with reference to these provided attributes (Bevan, 1999); whereas, quality-in-use as defined by ISO (2001 - ISO/IEC 9126-1) is *"the user's view of the quality of the software product when it is used in a specific environment and a specific Context-Of-Use"* (Botella, *et al.*, 2004, p. 3).

Quality Group Name	Quality Measure Name
Internal Quality Measures	Functional Adequacy
	Precision
	Restartability
	Physical Accessibility
External Quality Measures	Computational Accuracy
	Access Controllability
	Operational Consistency
	Installation Flexibility
Quality in Use Measures	Task Completion
	Productive Proportion
	Discretionary Usage

Table 5.3: WG6 proposed set of Quality Measures

Abran et al. (2005, p.5)

ii. Testing

When it is confirmed that the development phase which encapsulates the software quality checks is completed, the next major phase will be software testing. In the opinion of several authors, the testing phase is made up of two key activities known as Alpha and Beta testing (Puntambekar, 2007; Atwood, 2008; McDonough, 2011). These terms are widely used in most literature on software testing and are heralded by the pre-alpha and pre-beta phases. The pre-alpha phase includes all the activities carried out before the testing phase, i.e., investigating the development requirements, de-bugging, code optimisation, software development, and preliminary *"unit"* completion. The pre-Beta phase therefore encapsulates all software development processes up to the alpha testing.

⌛ *Alpha Testing*

Also known as internal or in-house testing (Atwood, 2004; McDonough, 2011), Alpha testing entails testing the version of the completed software by a customer at the developer's site (in a controlled environment) under the supervision of the developer (Puntambekar, 2007, p.30). It is imperative that the person to carry out the alpha test is any person other than the software engineer or the developer (Atwood, 2004). This enables the developer take record of errors and problems (Puntambekar, 2007). In some cases, this is referred to as the alpha release of the software, although it should be ensured that at this stage that the software does not get accessed by the public (McDonough, 2011). The deliverable of this phase is an Alpha Tool or the *"Pioneer edition"* of the software (Saleh 2009, p.26).

⌛ *Beta Testing*

According to Puntambekar (2007), this simply means allowing the software to be tested by a customer in the absence of the developer, though it is mostly performed within the developer's site, but sometimes outside the developer's environment by a person of trust. Thus, the environment is not controlled by the developer; although the substance is not whether the testing is conducted within or outside the developer's environment. As noted by McDonough (2011), the objective is to engage those outside the organisation in the testing process, so as to gather as much unbiased feedback as possible, without permitting public access to the software. The tester is however obliged to record the software performance and pass same to the developer for further revision.

In practice, once this stage is completed the software (now known as *"Betas"*) is given some wider access to specific group of persons. As noted by Atwood (2004), Betas are either limited to some defined users or they can even be open to the general public. Although the software at this stage is aimed at being feature complete, this does not eliminate the possibility of errors and bugs (Atwood, 2004). Debugging is the predominant activity associated with this stage; the aim being to correct errors through fixing (debugging) same. Finally, after a period of feedback collection and improvement, known as passing the software through integration test plans, the product at this point is called an integrated software.

iii. Release candidate

Known as installation (Saleh, 2009) or production / *"going live"* (Langer, 2012) or software releasing (McDonough, 2011), at this stage the software is considered as ready for final release. As pointed out by Anthe (2005) (a release manager at Microsoft), Release To Manufacturing (RTM), entails the process of making CDs, putting them in a box, then getting them out to customers for purchases. This is different from Release To Web (RTW), which means making a software available for free download. Either of these two approaches denotes the software release phase.

The last but infrequently used term in the SDLC is the gold phase. It is believed that this stage actually forms part of the release candidate, but Atwood (2004) strongly argues that this stage is distinct. The author proposes same based on the opinion that at this stage, developers no longer aim at improving on or supporting the tool, rather producing higher versions or entirely new models. This is actually a form of revision; however, it is focused on rekindling the desire of users to purchase what is promoted as a new release which must have eliminated identified bugs and errors associated with the previous version(s) or model(s).

iv. Maintenance

The SDLC is not complete without the maintenance phase. As proposed by Glass (2003), at any point from the software post-release phase, the software should be subject to maintenance. The author backed up this position by referring to the evolution of the word *"software"* in which the soft denotes possibility of revision. According to Glass (2003, p.115), software programs are *"an extremely malleable product, in part because it is so intangible"*. Product maintenance actually falls under the management plan of any software engineering organisation.

5.2 The i-Water Benchmarking Tool development

5.2.1 VBAProject Components

The VBA being an object-oriented programming language, *i*-Water Benchmarking Tool.xlsm VBAProject is made up of three major components, *inter alia*: Microsoft Excel Objects, Forms and Modules. The *"Microsoft Excel Objects"* are broken down into Sheet1 (Home page), Sheet2 (About the *i*-Water Tool), Sheet3 (Terms of Use), Sheet4 (Database), Sheet5 (Data Entry Sheet), Sheet6 (Data Entry Sheet.), Sheet7 (Data input and Validation), Sheet8 (Benchmarking Results) and ThisWorkbook. Accordingly, the *"Forms"* component comprises of: frm_Application_information, frm_Config_Charts, frm_Benchmarking_Specifics, frm_Benchmarking_Start_Form, frm_Contact_Information, frm_DataSampleFormat1, frm_DataSampleFormat2, frm_Process_Assessement and frm_Tool_Operation; whereas, the *"Modules"* component which is the last component of the VBAproject is composed of: Mod_CHART_Functions, Mod_MAIN_Functions and Mod_OTHER_Functions. Functionalities of these project objects and procedures are detailed in the succeeding section.

5.2.2 Functionalities of the i-Water Tool's objects and procedures

i. The "Home page" and "Tool description, purpose and terms" form

The Home page of the *i*-Water Tool (Figure 5.4) serves as the tool's dashboard. When the Tool is launched, the first page that appears is the Home page; however, the Home page remains inaccessible until the *"Tool description, purpose and terms"* form is processed. This requires accepting the conditions associated with using the Tool by clicking the *"Start Wizard"* tab, or declining same by clicking the *"Exit Wizard"* button which closes down the application. Forcing this dialogue box to appear when the Tool is launched is considered in VBA as a trigger function, and the procedure for it is written in the *"ThisWorkbook"* Microsoft Excel object (Appendix B, subsection 9.1.1). Figure 5.3 reveals the *"Tool description, purpose and terms"* form.

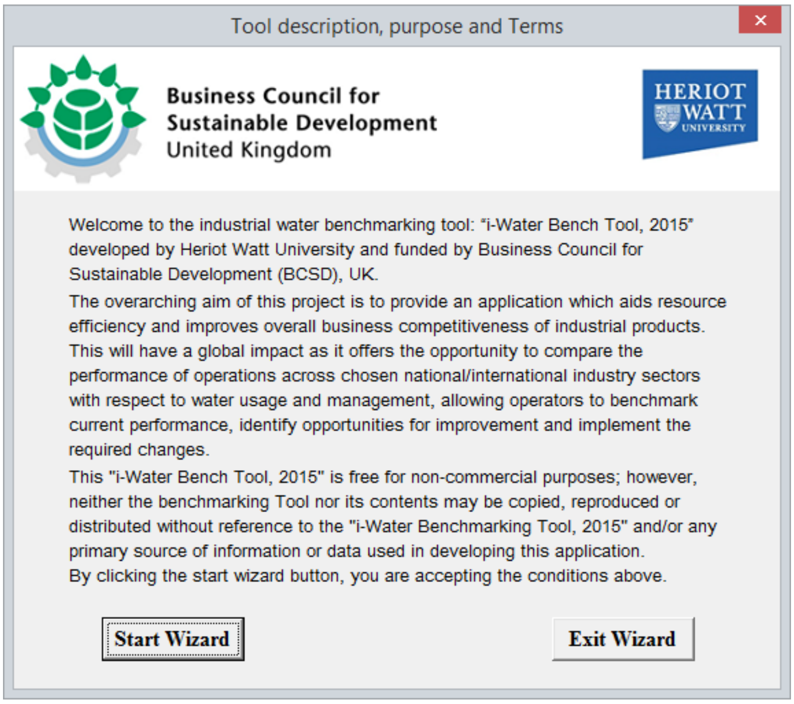


Figure 5.3: Tool description, purpose and terms form

For the Home page, on its top are revealed the logos of the funder (UK Business Council for Sustainable Development) and the developer's institution (Heriot Watt University); these are direct links to websites of these bodies. Macros for UK–BCSD and Heriot Watt University websites are contained in Appendix B in the Mod_OTHER_Functions (subsection 9.1.18) as Open_Heriot_Watt_Website_Click() and Open_UKBCSD_Website_Click() respectively. The next item on the Home page is the name and current version of the Tool. Lastly, the Home page holds three customised *"Form controls"* buttons; these are: About the *i*-Water Tool, Terms of use and liability and START buttons. Whereas, each of these buttons is linked to a separate VBA Object or Form, their functionalities will be expounded when the associated Objects or Forms are explained.

Figure 5.4: *i*-Water Tool Home page

ii. About the i-Water Tool

Though considered as an industry-specific research, development of this software being an academic endeavour requires that both the industry and academic requirements are met. Such requirements include proper introduction and explanation of the project, and the rationale behind it; that is, identification of the research gap and accurate referencing of information or data sources that are directly or indirectly used in the development of the Tool, based on their terms of use. The *"About the i-Water Tool"* page therefore captures these details and ends up with a comprehensive reference list of the Tool's information / data sources. Because of the length of its details, contents of the *"About the i-Water Tool"* is neither added to this section nor included in the appendices; it is on this note left in the Tool.

iii. Terms of Use and Liability Policy

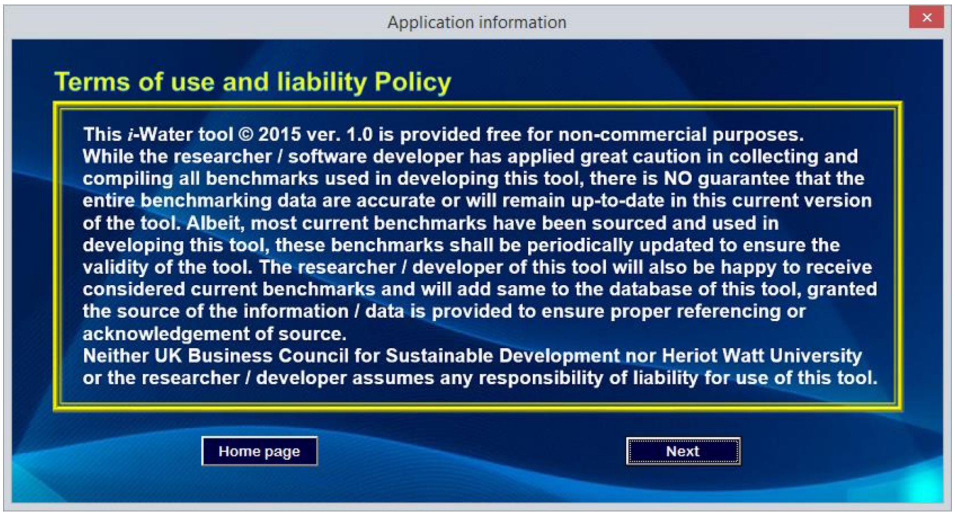


Figure 5.5: Terms of Use Form

Figure 5.5 reveals the Terms of use and Liability Policy of the *i*-Water Tool. This information is contained both in the Terms of Use page which is a Microsoft Excel Object and in a Form. The idea is that though it is expected that users of any software should read the *"Terms"* of any software use before using same, but it is not impossible for a user to avoid clicking on the *"Terms of Use and Liability Policy"* button which should open the appropriate page. To this end a separate form known as the frm_Tool_Operation is created to pop up once a user clicks the start button, and to avoid any attempt to bypass the decision to accept or otherwise, the close *"X"* function is programmatically disabled. Clicking the *"Next"* button exculpates UK_BCSD, Heriot Watt University or the Developer of any responsibility of liability for use of this Tool.

iv. Database of the Benchmarking Tool

The Database of the Tool contains benchmarks that are used to compare the water use performance of various industrial sectors, divisions and processes. Currently, it holds 800 industrial water use benchmarks that were successfully collected from several sources – standards, industry benchmarks, trade bodies' publications, sustainability / benchmarking Tools, and textbooks. These benchmarks cover 786 industrial processes and 43 industrial divisions of the 5 industrials sectors chosen for this research. On the Database page, each benchmark is properly referenced and the copyright conditions of these benchmarks are provided for the key reason of ethics.

Suffice it that contents of the Database (the Benchmarks) are neither contained in this section nor are they incorporated into appendices on grounds of size or enormity of information. They are retained in the Tool accordingly.

v. Benchmarking Start Form (frm_Benchmarking_Start_Form)

During operation of the *i*-Water Tool, just after the *"Terms of Use and Liability Policy"* form exits, the *"Benchmarking Start Form"* appears. This form is considered as the Tool's main menu; it reveals four major benchmarking steps: A. Contact information, B. Benchmarking specifics, C. Data entry and validation, and D. Benchmarking results. These milestone steps basically follow the above order; that is, users are not permitted to access the Benchmarking Results sheet, which is the last step on this form, without first going through the other three steps. This helps to check errors in processing information using this Tool. On the right side of the form is a brief guide or instruction or user support. Figure 5.6 reveals the Benchmarking Start Form.

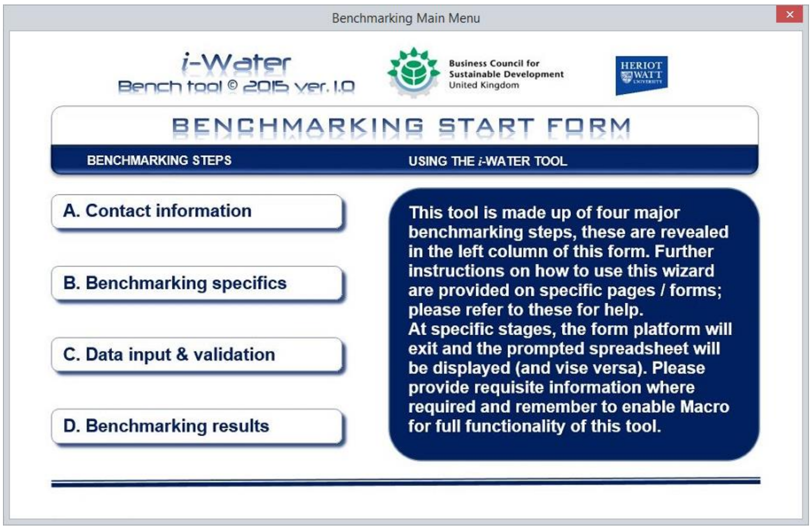


Figure 5.6: Benchmarking Start Form

vi. Contact Information

Being the first tab on the Benchmarking Start Form, clicking the Contact Information button displays the Contact Information form. The form comprises of Text boxes, list boxes, command boxes, labels, etc. that are set to collect the contact information associated with the benchmarking organisation. Information collected from this form is then transferred to the benchmarking results sheet. Figure 5.7 reveals the Contact Information form.

Figure 5.7: Contact Information Form

vii. Benchmarking Specifics

The Contact information form's Next button is programmed to lead the user to the benchmarking specifics form. This form does the benchmarking exercise proper. It accesses the database and extracts the selected sector, division, segment and production process. Here, the industrial sector is divided into two: Manufacturing and Thermoelectric power. Benchmarks of these industrial sectors are all contained in the database. Once the appropriate production process is selected, the user is to select the corresponding Key Performance Indicator (KPI) and Benchmarking Unit. Suffice it that two major KPIs may be found in the dropdown list. These are the Water use per unit product (Relative) and Water use (Absolute); and as the names implies, the Water use per unit product implies water use per unit of the product (finished), while water use absolute denotes water use per period of time: diurnally, weekly, monthly, quarterly, yearly, biannually, etc.

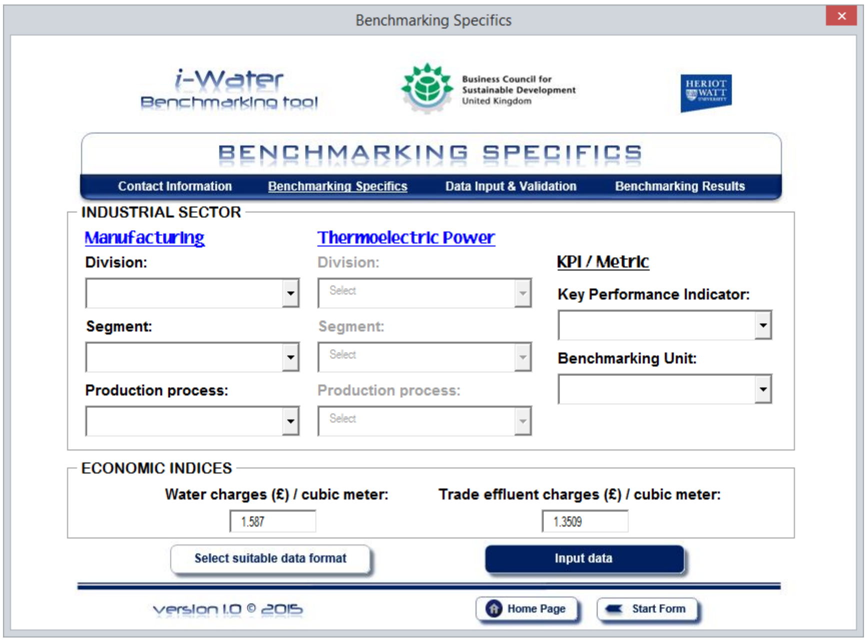


Figure 5.8: Benchmarking Specifics Form

Further, the *"Economic indices"* segment is the second part of the benchmarking specific form. Here the user is expected to provide the current cost of water [Water charges (£) / cubic meter] and the wastewater treatment cost [Trade effluent charges (£) / cubic meter]. This is used to calculate the financial savings or expenses accruable per unit of benchmarked product. Information extracted using this form is sent directly to the benchmarking results sheet. Figure 5.8 reveals the Benchmarking Specifics Form.

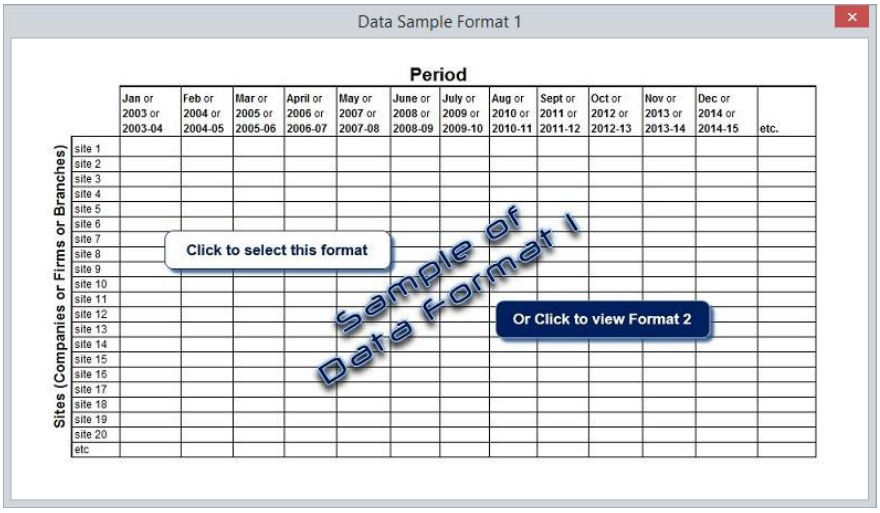


Figure 5.9: Data Sample Form 1

Still on the Benchmarking Specifics Form, to transfer the requisite information or data to the appropriate sheet, the user needs to click the Input Data button. However, when this is clicked, a message box pops up, prompting the user to select the applicable data format. Two data formats are used in this Tool, these are revealed as Figure 5.9 and

5.10. These forms help present the data formats that are acceptable in the Tool. Once either of these formats is selected, the Wizard then directs the User to click the Input Data tab; clicking same then displays the data entry sheet based on the selected format.

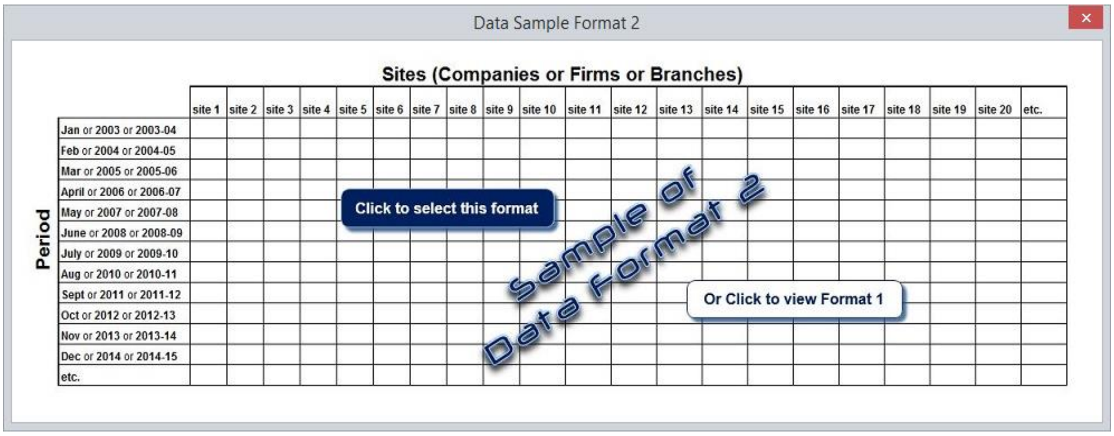


Figure 5.10: Data Sample Form 2

viii. Data entry sheets

There are two Data entry sheets in the Tool; these give the User the flexibility of decision regarding the data format. By this it means that the data may come in the format of the companies for comparison being arranged horizontally, while the period is vertically aligned, or vice versa. Irrespective of the selected data format and the data entry sheet in used to enter the benchmarking data, the Wizard is able to collect the data and transfer to the Data input and Validation page.

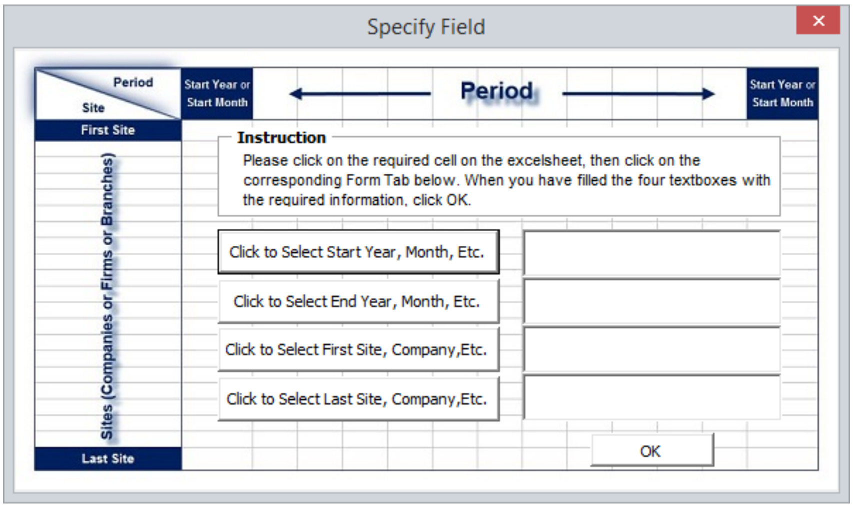


Figure 5.11: Specify Field Form 1

To collect the entered data and pass same into the Data and Validation sheet, the user clicks the *"Display cells' selection form"* to engage the *"Specify Field"* Forms. These again are two in number (see figures 5.11 and 5.12) and apply to the data format selected. Once the start and end years and the companies or firms under consideration are selected and the OK button is clicked, then the Data input and Validation sheet will be displayed.

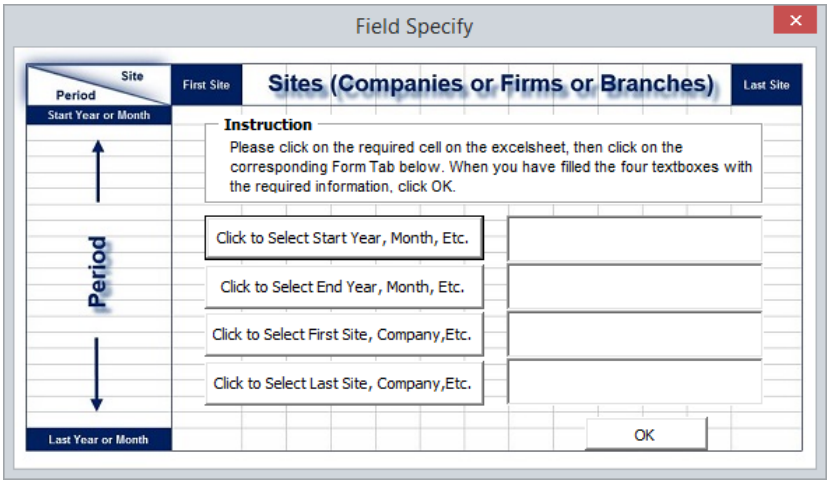


Figure 5.12: Specify Field Form 2

ix. Data input and Validation

Considered as one of the most important parts of the Tool, the Data input and Validation page is where data is treated and made ready for analysis. This is achieved by scanning through each cell in search of special characters that are capable of crashing the tool, or at least leading to errors. The *"Benchmark"* tab is contained in this sheet; however, the tab remains disabled until the data is validated. The *"Validate entry"* tab helps to check anomalies such as special characters and objects. It is also important to state that further error checking is contained in the procedures for the *"Benchmark"* operation; this is incorporated to ensure that even after a data is validated, where the user still deliberately or inadvertently introduces any special character or object into any cell, such will still be removed before the analysis is carried out.

x. Benchmarking results

After data contained in the Data input and Validation Page is validated and the Benchmark button is clicked, the Configure Charts form is displayed. This helps in selecting the range of sites for the comparison, and the specific year of interest. Selection of a specific year of interest will enable more detailed scrutiny of the benchmarked organisation's performance for the selected specific year. Figure 5.13 is the Configure Charts form.

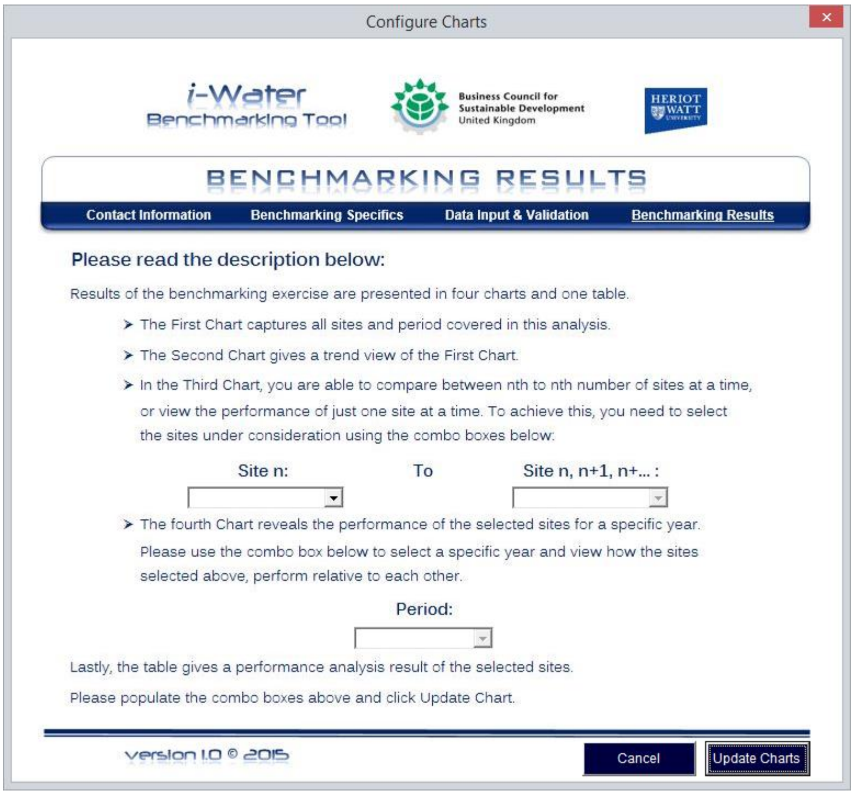


Figure 5.13: Configure Charts Form

On the benchmarking Results sheet, four charts are provided; these include two charts with the title *"Benchmarking output for all entries"*. The first being the output of the entries in bars while the second is the same output as a trend. The third chart is the *"Benchmarking output for selected sites"*; this is the chart that is configured based on the sites selected using the Configure Charts Form. The last chart on the results sheet is a pie chart captioned: *"Water use split for a specific Year"*. This chart is plotted for a specific selected year and provides the water use percentages for the benchmarked organisations.

It is paramount to state that the Benchmarking Results sheet is divided into two. The first is the output of the Metric Benchmarking, while the second is the result of the process benchmarking. Charts contained in the Benchmarking Results sheet are the product of the Metric benchmarking exercise; to display the process benchmarking form, the user then clicks the *"Benchmark your processes"* tab. The process benchmarking form is revealed below as figure 5.14. Development of the form was informed by the need to capture best practice associated with the technical, regulatory and managerial aspects of organisations. Thus, the form covers four key subjects of the water savings measures, they are: Operational services; Maintenance, Government Policies; Staff education and awareness. These four major best practice water savings measures have been sub-detailed into 40 points. Each point is presented as a question. The information used in forming these questions where sourced from reports by the following authors: Griggs (1998); Bruni (2013) and WRAP (2013a).

Qualitative assessment

Process performance assessment form

Benefits of industrial water conservation include cost and energy savings associated with water and wastewater treatments; minimised environmental impacts and overall competitiveness of industrial products.

Please provide answers to the questions below to gain a clearer understanding of how your organisation is performing in terms of its water use for industrial processes.

Operational Strategies

1. Do you conduct general water audits in your organisation?
   - ☐ Yes ☐ No
   - If yes, how often?
   - ☐ Monthly ☐ Quarterly ☐ Half-Yearly ☐ Yearly ☐ Others, please specify

2. Do you benchmark your performance against those of comparable organisations?
   - ☐ Yes ☐ No
   - If yes, how often?
   - ☐ Monthly ☐ Quarterly ☐ Half-Yearly ☐ Yearly ☐ Others, please specify

3. Do you currently use any tool or software to track your water use and help identify potential savings?
   - ☐ Yes ☐ No

4. Do you have a water conservation checklist in your organisation?
   - ☐ Yes ☐ No
   - If yes, how often are they used?
   - ☐ Monthly ☐ Quarterly ☐ Half-Yearly ☐ Yearly ☐ Others, please specify

5. Are standalone or computer-interfaced data loggers or data acquisition systems currently part of your organisation's water system?
   - ☐ Yes ☐ No

6. As an alternative to single – flow tank systems for industrial rinsing and washing, do you use a counter – current system in your organisation?
   - ☐ Yes ☐ No ☐ N.A.

7. Do you have any rainwater harvesting system in your organisation?
   - ☐ Yes ☐ No

8. Water-free systems are great cost and energy efficient alternatives to water using products (WUPs); please select from the list below the system(s) presently used and promoted in your organisation in form of or part of your water management plan.
   - ☐ Ambient air cooling
   - ☐ Use of brushes for cleaning
   - ☐ Use of chemicals for stain removals, as solvents, etc.
   - ☐ Use of heat
   - ☐ Any other; please specify:

9. What type of urinals are currently in use in your organisation?
   - ☐ Cyclical flushing type ☐ Occupancy detector type ☐ Motion sensor flush type

10. How are your taps operated?
    - ☐ Manually ☐ Automatic closure ☐ Sensor activated

11. Do you know the actual cost of water supplied to your organisation, or have a good understanding of your water use bills / rates?
    - ☐ Yes ☐ No

12. Is steam from boiler condensed and reused in the boiler to reduce the required make-up water?
    - ☐ Yes ☐ No

13. Is your meter reading a fixed (scheduled) activity?
    - ☐ Yes ☐ No
    - How often do you take the readings?
    - ☐ Monthly ☐ Quarterly ☐ Half-Yearly ☐ Yearly ☐ Others, please specify:

14. For cleaning processes that indispensably require water, do you use automatic shut-off sprays or very-low-water pressurized spray nozzles?

☐ Yes ☐ No

15. How do you currently move your industrial waste? Using:

☐ Water ☐ Air ☐ Other means excluding water ☐ Combination of methods

16. Are flow restrictors currently incorporated into your tap system?

☐ Yes ☐ No

17. Is a Building Management System (BMS) part of you water system?

☐ Yes ☐ No

18. Are the WCs in your organisation currently replaced with low water flush WC types?

☐ Yes ☐ No

Maintenance

19. Do you have a diagnostic checklist?

☐ Yes ☐ No

20. How often do you conduct checks on your water system for leaks, faults and aged parts?

☐ Monthly ☐ Quarterly ☐ Half-Yearly ☐ Yearly ☐ Others, please specify:

21. How do you check your leaks?

☐ Manually ☐ Using automatic leak detectors

• If you have automatic leak detectors as part of your water system, do they also automatically trigger shut – off of water flow through affected areas?

☐ Yes ☐ No

22. Does your water management plan include water use performance comparison of equipment and upgrade consideration?

☐ Yes ☐ No

Governance Polices

23. Do you currently have an Environmental Management System in your organisation to help measure, monitor and analyse your environmental performance and ultimately minimise the environmental impacts of your operations (processes)?

☐ Yes ☐ No

24. Is water conservation part of your organisation's operational or governance polices?

☐ Yes ☐ No

25. Water conservation can be greatly enhanced through the application of the 3 R's of resource management: Reduce, Reuse and Recycle. As it is true that not all industrial processes require water of drinking water standard or quality, such as water used for cooling and for some ancillary services. Do you currently have a water reuse scheme in your organisation?

☐ Yes ☐ No

26. At present, do you presently use water treatment schemes such as Reverse Osmosis systems; MBRS, Activated

☐ Yes ☐ No

27. Is your water use performance reported to stakeholders (internal and external) for reviews and possible suggestions of further improvement strategies?

☐ Yes ☐ No

28. Do you currently have set water use benchmarks for your industrial operations and processes?

☐ Yes ☐ No

29. Do you have water supply meter(s) installed for water measurement and monitoring?

☐ Yes ☐ No

30. Are departments within your organisation sub-metered to identify sections or processes that use water most?

☐ Yes ☐ No

31. Do you have a water use inventory in your organisation?

☐ Yes ☐ No

• If yes, how often is this updated?

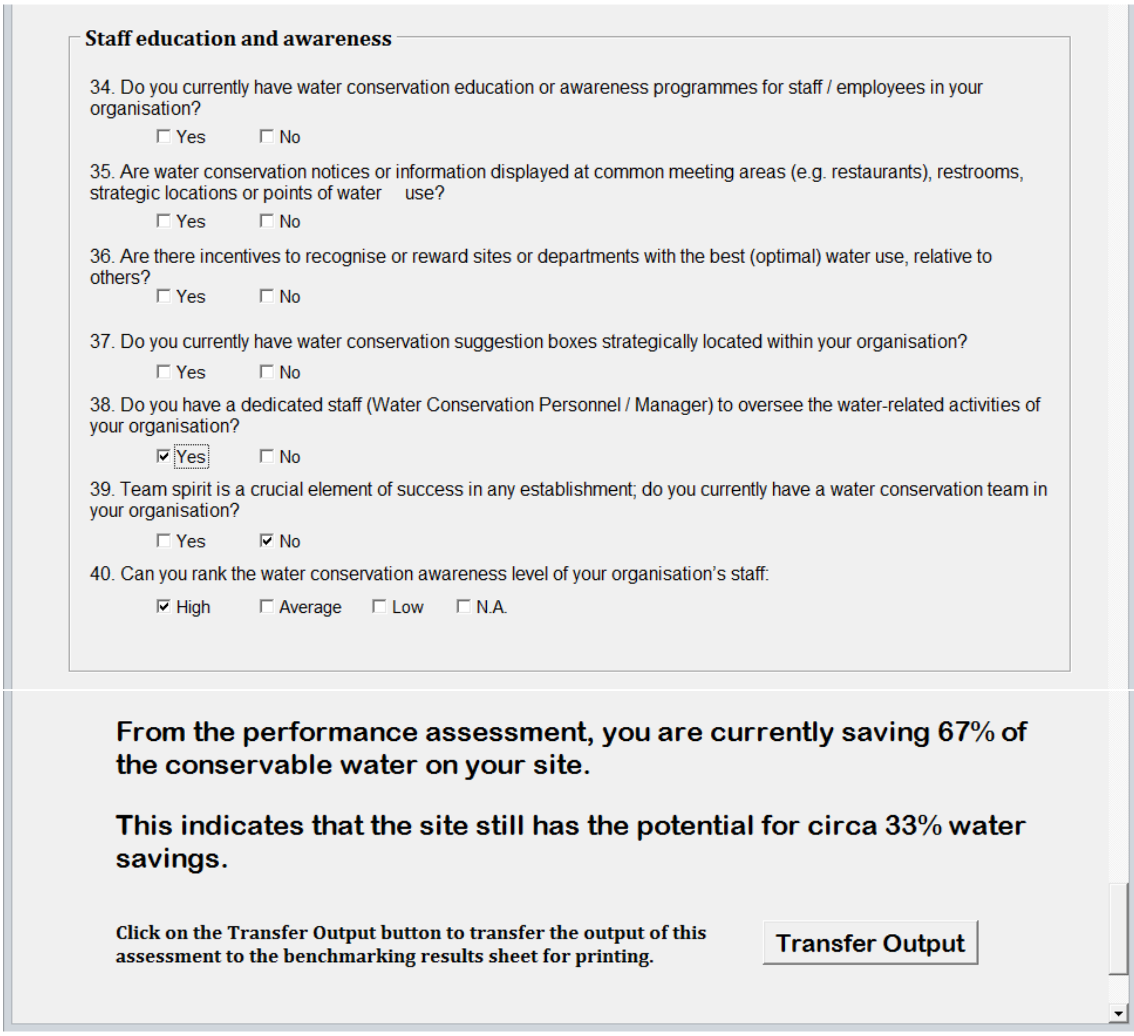
☐ Monthly ☐ Quarterly ☐ Half-Yearly ☐ Yearly ☐ Others, please specify:

32. Do you specifically have an inventory of water consumption rates by the WUP's (Water-Using Products) in your organisation?

☐ Yes ☐ No

33. If you have water usage data over a period of time, in what form are these stored?

☐ Water use per unit product ☐ Total water use per period



Staff education and awareness

34. Do you currently have water conservation education or awareness programmes for staff / employees in your organisation?

☐ Yes ☐ No

35. Are water conservation notices or information displayed at common meeting areas (e.g. restaurants), restrooms, strategic locations or points of water use?

☐ Yes ☐ No

36. Are there incentives to recognise or reward sites or departments with the best (optimal) water use, relative to others?

☐ Yes ☐ No

37. Do you currently have water conservation suggestion boxes strategically located within your organisation?

☐ Yes ☐ No

38. Do you have a dedicated staff (Water Conservation Personnel / Manager) to oversee the water-related activities of your organisation?

☑ Yes ☐ No

39. Team spirit is a crucial element of success in any establishment; do you currently have a water conservation team in your organisation?

☐ Yes ☑ No

40. Can you rank the water conservation awareness level of your organisation's staff:

☑ High ☐ Average ☐ Low ☐ N.A.

From the performance assessment, you are currently saving 67% of the conservable water on your site.

This indicates that the site still has the potential for circa 33% water savings.

Click on the Transfer Output button to transfer the output of this assessment to the benchmarking results sheet for printing.

Transfer Output

Figure 5.14: Qualitative assessment form

Adapted from: Griggs (1998), Bruni (2013) and WRAP (2013a)

As the user checks and fills the applicable buttons and textboxes of the qualitative assessment form (Figure 5.14), the Wizard calculates the performance of the benchmarked organisation based on the answers provided. Thus, if one answer is provided, the Wizard will calculate the performance of the organisation exclusively based on the answer provided. This way the user is able to provide answers to questions considered applicable to the organisation that is benchmarked. A typical demonstration of this capability of the form is revealed in figure 5.14 where based on the three buttons that are checked, the Tool is able to carry out the process benchmarking assessment and present the performance status of the organisation.

xi. The VBA modules

In developing the *i*–Water Tool, several codes were written, these codes are positioned behind the Microsoft Excel Objects, Forms and procedures. The Microsoft Excel Objects and Forms have been detailed in the previous setions of this chapter, however, the last component being the modules are contained in the appendices because of their extensive details. The Mod_CHART_Functions contain the procedures that control the charts in this Tool and are revealed as Appendix B, sub-section 9.1.16. The Mod_MAIN_Functions are macros that control functions such as getting the unique entries from the database, data validation and the display / operation of the field specify form; these are revealed in the appendices as Appendix B, sub-section 9.1.17. The last module encapsulates general procedures such as those that hide and display individual sheets, website links to the UK-BCSD and Heriot Watt University, and the macro that closes down the *i*-Water Tool and opens a new one with a unique name. The name of this module is: Mod_OTHER_Functions and its subroutines constitute Appendix B, sub-section 9.1.18.

5.3 Benchmarking Tool Application

5.3.1 Performance assessment using benchmarking tool

With the overarching aim of producing a tool that will aid resource efficiency and improve overall business competitiveness of the industry water users, data collected for this study were first analysed using the developed *i*-Water Tool. This is to help in validating/standardizing the tool before it is put up on the WBCSD website for public access and use. Further, analyses conducted as part of this research will establish the current performance of UK industrial subsectors, identify opportunities for improvement and most suitable ways of implementing the requisite changes.

During application, as the user provides requisite information on the area of benchmarking interest, the tool automatically sieves out the industrial sectors, divisions and processes to the specific appropriate benchmark value, and plots this in a graph relative to the data provided by the benchmarking organisation(s). Finally, performance of the benchmarked organisations is presented in a graphical form.

As the tool is developed to enable benchmarking of both quantitative and qualitative processes in water utilities, for this study three major quantitative benchmarking assessments are detailed; they include:

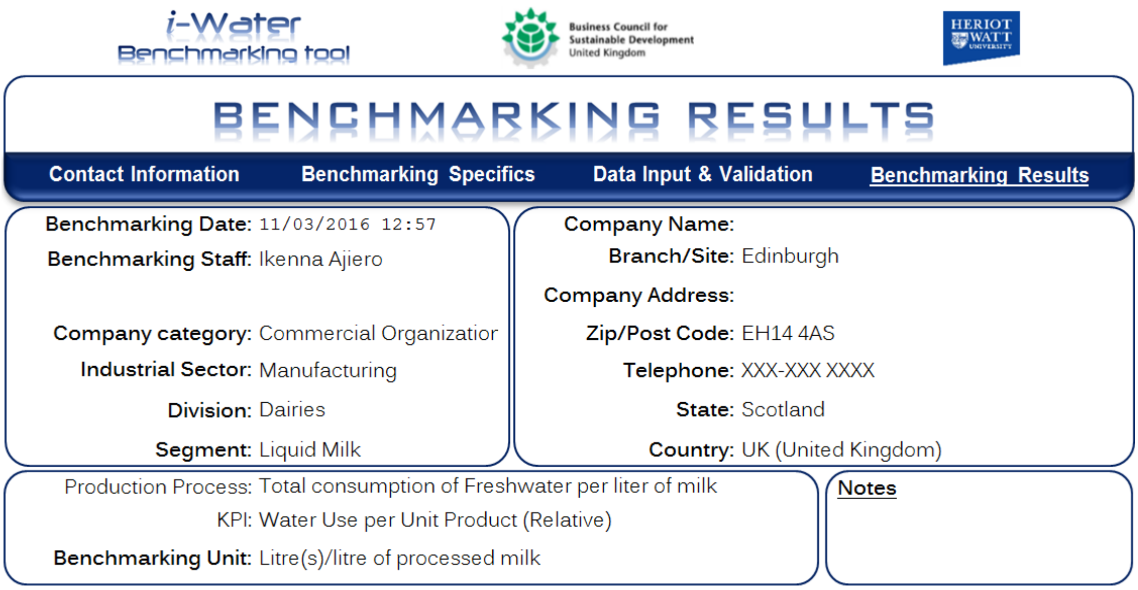
- Establishing the water use performance trend of each subsector on a periodic basis, based on segmentation of the collected data.
- Comparing the performance of the subsectors against industry benchmarks, in order to identify opportunities for water savings.
- Comparing the performance of one subsector against others to ascertain the most waster intensive processes or subsectors.

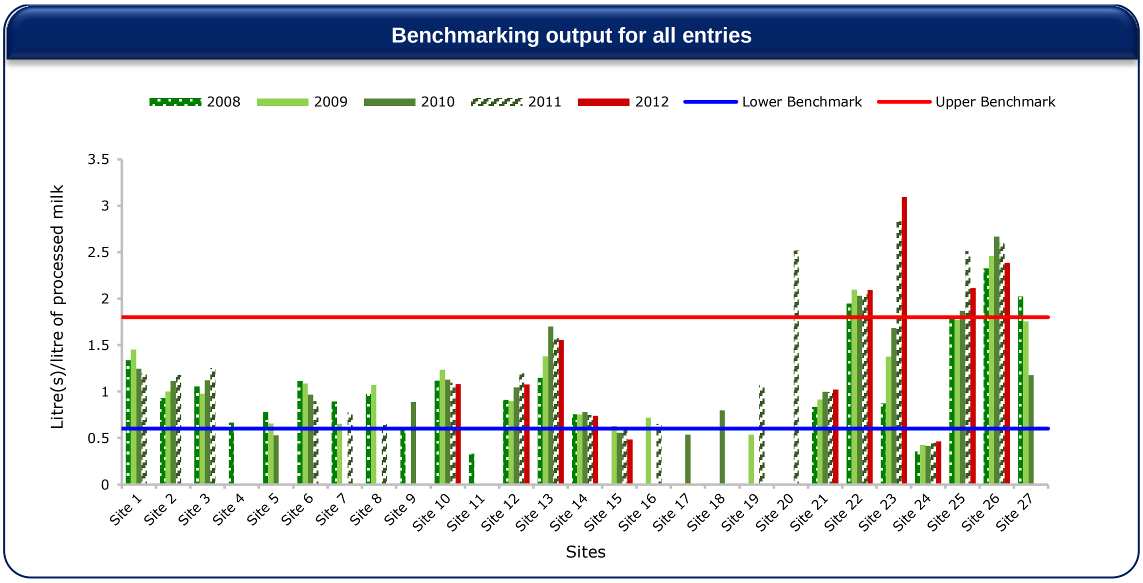
These proposed features are verified using the completed benchmarking Tool and results of the quantitative assessment are presented below. Data used for this performance were collected from trade bodies, results presented here only form the descriptive statistics or data summary for the test of hypothesis 3. The inferential statistics is contained in Chapter six.

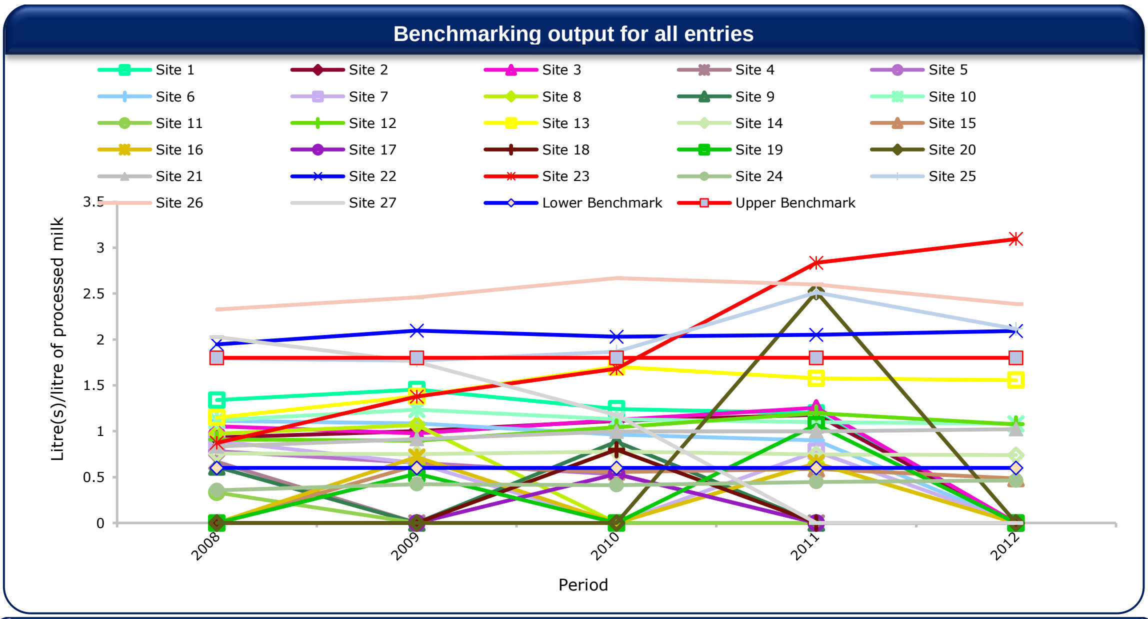
5.3.2 Results of the performance benchmarking exercise

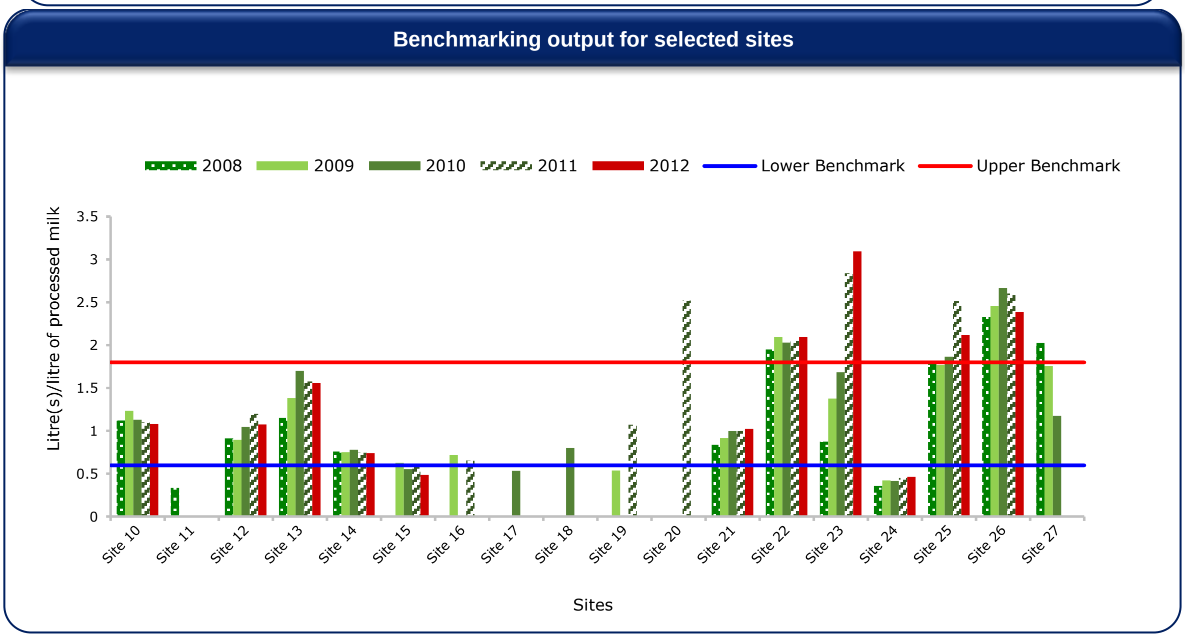
As part of the data analyses for this study, the figures below reveal results of a benchmarking exercise conducted using data collected from the Diary industrial sector. Three key Dairy subsectors where benchmarked, these include: Liquid milk, Cheese and Butter. Data collected for these analyses are the normalised data; that is, water use per unit product or production. Being a descriptive statistics, these outputs serve as data summary of annual water use (relative to production) by UK production (manufacturing) companies.

i. Water use benchmarking for Liquid Milk production




Benchmarking output for all entries
2008
2009
2010
2011
2012
Lower Benchmark
Upper Benchmark
Litre(s)/litre of processed milk
0
0.5
1
1.5
2
2.5
3
3.5
Site 1
Site 2
Site 3
Site 4
Site 5
Site 6
Site 7
Site 8
Site 9
Site 10
Site 11
Site 12
Site 13
Site 14
Site 15
Site 16
Site 17
Site 18
Site 19
Site 20
Site 21
Site 22
Site 23
Site 24
Site 25
Site 26
Site 27
Sites


Benchmarking output for all entries
Site 1
Site 2
Site 3
Site 4
Site 5
Site 6
Site 7
Site 8
Site 9
Site 10
Site 11
Site 12
Site 13
Site 14
Site 15
Site 16
Site 17
Site 18
Site 19
Site 20
Site 21
Site 22
Site 23
Site 24
Site 25
Site 26
Site 27
Lower Benchmark
Upper Benchmark
Litre(s)/litre of processed milk
0
0.5
1
1.5
2
2.5
3
3.5
2008
2009
2010
2011
2012
Period


Benchmarking output for selected sites
2008
2009
2010
2011
2012
Lower Benchmark
Upper Benchmark
Litre(s)/litre of processed milk
0
0.5
1
1.5
2
2.5
3
3.5
Site 10
Site 11
Site 12
Site 13
Site 14
Site 15
Site 16
Site 17
Site 18
Site 19
Site 20
Site 21
Site 22
Site 23
Site 24
Site 25
Site 26
Site 27
Sites

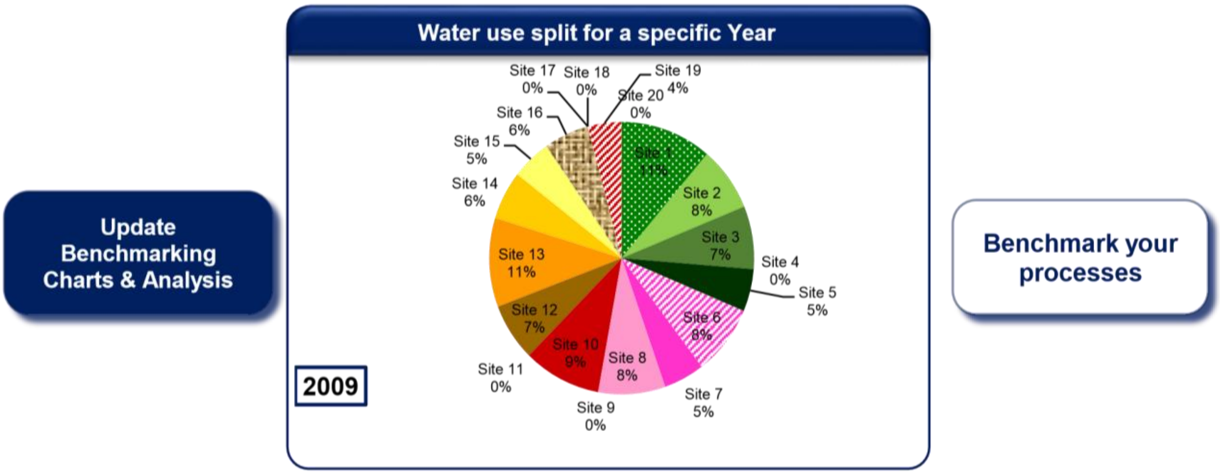


Figure 5.15: Benchmarking results of water use for liquid milk production

The pie chart above reveals the individual organisation's percentage share in the use of water in a specific year. For this pie chart, 2009 was selected; the chart then shows that Sites 1 and 13 used the largest volumes of the water, relative to other sites, for the year 2009. Selection of any other year will help reveal how each site used water in the considered year. This interpretation is applicable to the subsequent pie charts captioned: *"Water use split for a specific year"*.

Site	Average water use/unit Product	Rank 1 = Highest	Benchmark (Lower)	Deviation about Benchmark	Deviation Value (%)	Water charges (£)	Wastewater charges (£)
Site 1	1.31	3	0.60	0.71	54.2%	£ 0.0011	£ 0.0010
Site 2	1.06	6	0.60	0.46	43.2%	£ 0.0007	£ 0.0006
Site 3	1.10	5	0.60	0.50	45.6%	£ 0.0008	£ 0.0007
Site 4	0.67	16	0.60	0.07	10.2%	£ 0.0001	£ 0.0001
Site 5	0.66	17	0.60	0.06	8.6%	£ 0.0001	£ 0.0001
Site 6	1.02	8	0.60	0.42	41.0%	£ 0.0007	£ 0.0006
Site 7	0.78	12	0.60	0.18	22.6%	£ 0.0003	£ 0.0002
Site 8	0.90	9	0.60	0.30	33.1%	£ 0.0005	£ 0.0004
Site 9	0.75	14	0.60	0.15	19.8%	£ 0.0002	£ 0.0002
Site 10	1.13	4	0.60	0.53	47.1%	£ 0.0008	£ 0.0007
Site 11	0.33	20	0.60	-0.27	-80.1%	-£ 0.0004	-£ 0.0004
Site 12	1.03	7	0.60	0.43	41.5%	£ 0.0007	£ 0.0006
Site 13	1.47	2	0.60	0.87	59.3%	£ 0.0014	£ 0.0012
Site 14	0.76	13	0.60	0.16	20.6%	£ 0.0002	£ 0.0002
Site 15	0.56	18	0.60	-0.04	-6.3%	-£ 0.0001	-£ 0.0000
Site 16	0.69	15	0.60	0.09	12.7%	£ 0.0001	£ 0.0001
Site 17	0.54	19	0.60	-0.06	-11.9%	-£ 0.0001	-£ 0.0001
Site 18	0.80	11	0.60	0.20	24.8%	£ 0.0003	£ 0.0003
Site 19	0.80	10	0.60	0.20	25.4%	£ 0.0003	£ 0.0003
Site 20	2.52	1	0.60	1.92	76.2%	£ 0.0030	£ 0.0026

Nb. If cells in the table above are highlighted in Red, then the corresponding sites use water above the average

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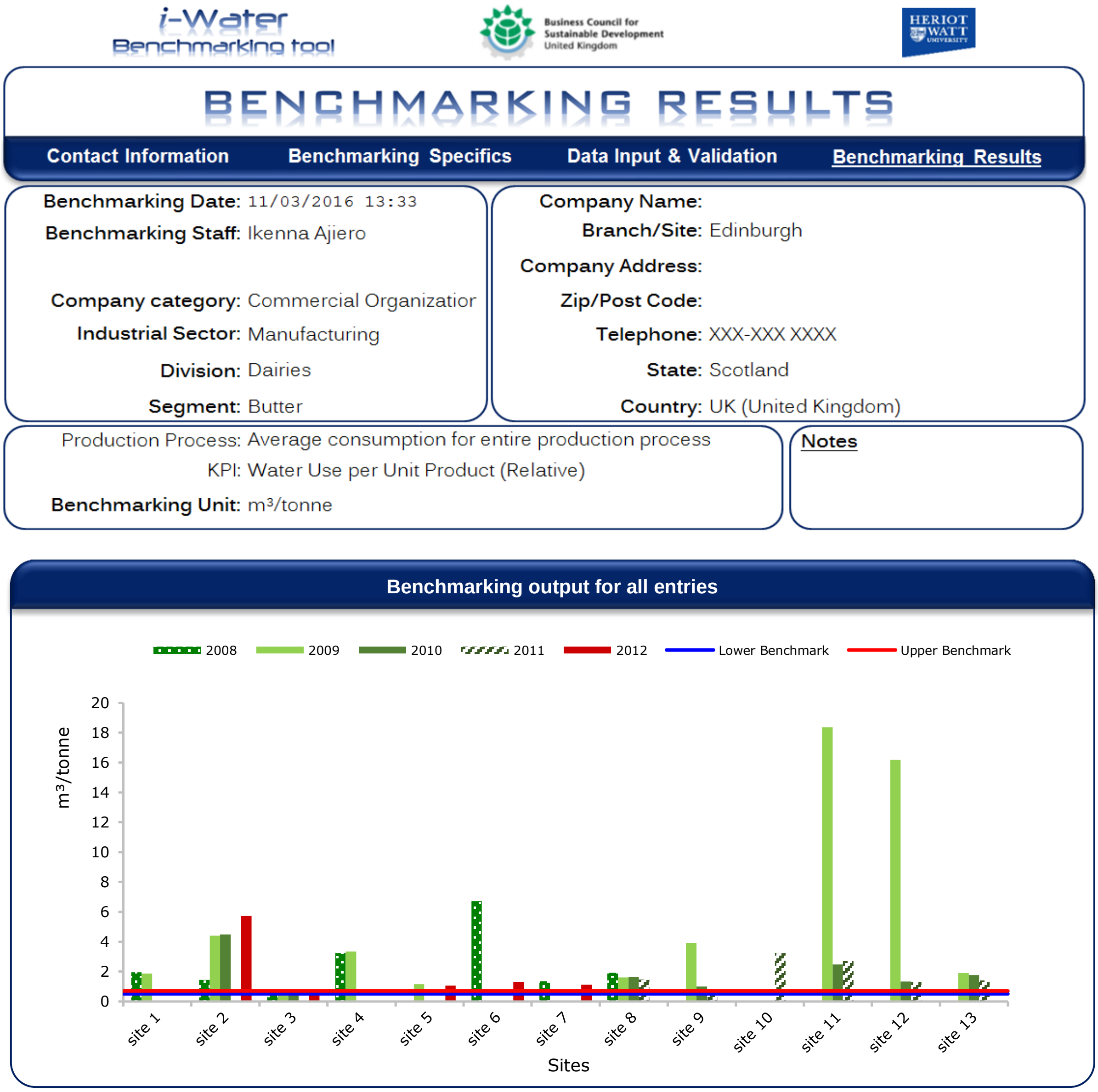
Table 5.4: Quantitative and economic water use performance results for UK liquid milk production

Figure 5.15 and table 5.4 reveal benchmarking results of the performance comparison among 27 liquid milk production companies. For purposes of confidentiality and anonymity, these companies have been assigned the names: Site 1, Site 2, Site 3, …n. From the first graph (Benchmarking output for all entries), it is seen that Sites 20 – 27 use water beyond the upper benchmark limit. Sites using water below the lower benchmark threshold are considered to be performing excellently, sites using water between the upper and lower limits are rated as average, while those above the upper benchmarking limit are categorized as performing poorly. From the assessment, it is seen that only Sites 11, 15 and 17 use water for liquid milk production excellently; Sites 1 – 19 use water averagely, while water use by Sites 20 – 27 is rated as *"Poor"*.

ii. Water use benchmarking for Butter production



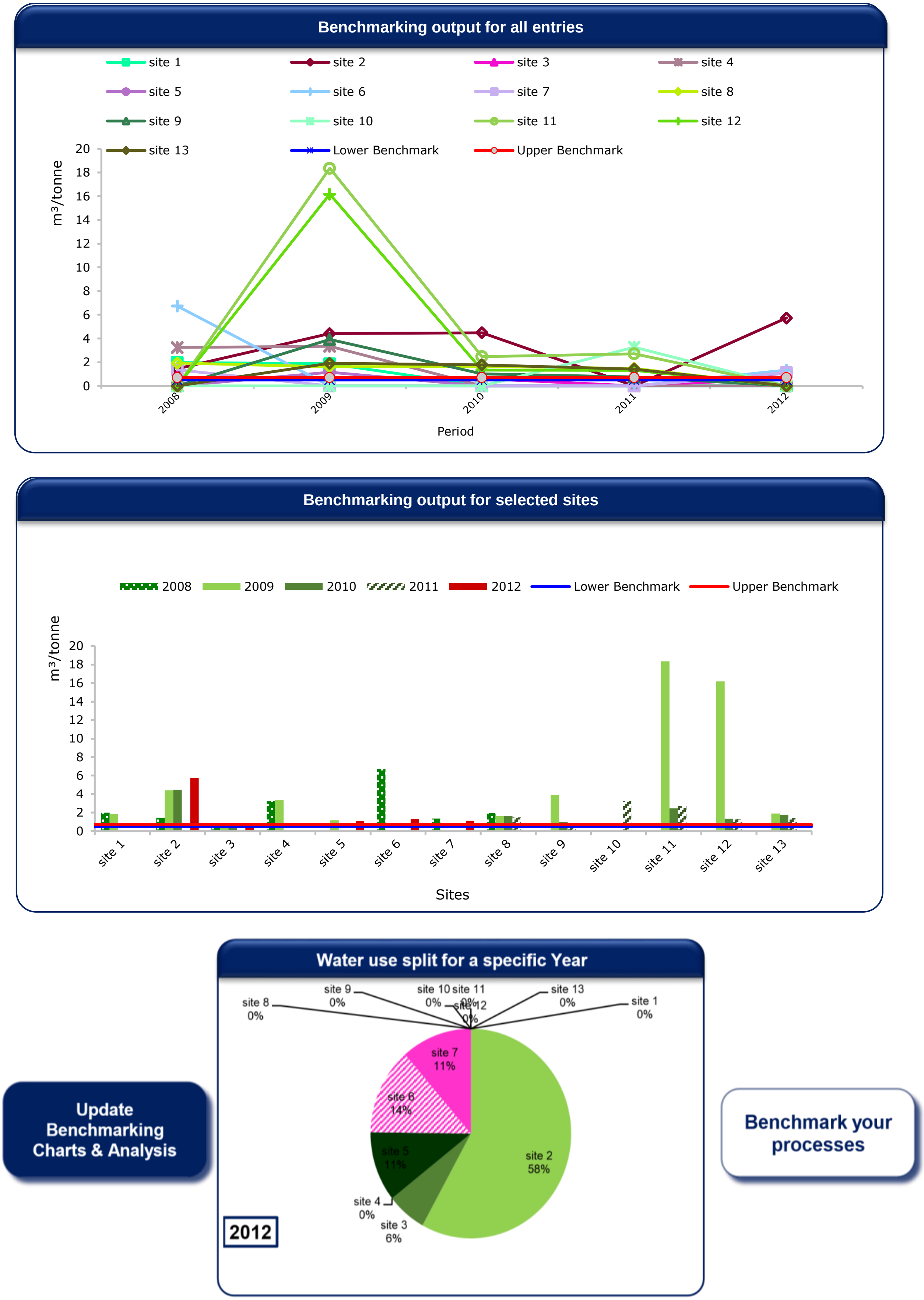


Figure 5.16: Benchmarking results of water use for UK butter production

Site	Average water use/unit Product	Rank 1 = Highest	Benchmark (Lower)	Deviation about Benchmark	Deviation Value (%)	Water charges (£)	Wastewater charges (£)
site 1	1.92	7	0.50	1.42	74.0%	£ 2.2547	£ 1.9193
site 2	4.02	4	0.50	3.52	87.6%	£ 5.5838	£ 4.7531
site 3	0.67	13	0.50	0.17	25.7%	£ 0.2740	£ 0.2333
site 4	3.29	5	0.50	2.79	84.8%	£ 4.4291	£ 3.7702
site 5	1.11	12	0.50	0.61	55.1%	£ 0.9731	£ 0.8284
site 6	4.03	3	0.50	3.53	87.6%	£ 5.6025	£ 4.7690
site 7	1.24	11	0.50	0.74	59.7%	£ 1.1767	£ 1.0016
site 8	1.67	10	0.50	1.17	70.1%	£ 1.8585	£ 1.5820
site 9	1.89	8	0.50	1.39	73.5%	£ 2.2053	£ 1.8773
site 10	3.27	6	0.50	2.77	84.7%	£ 4.3882	£ 3.7354
site 11	7.85	1	0.50	7.35	93.6%	£ 11.6582	£ 9.9238
site 12	6.27	2	0.50	5.77	92.0%	£ 9.1628	£ 7.7996
site 13	1.70	9	0.50	1.20	70.6%	£ 1.9032	£ 1.6201

Nb. If cells in the table above are highlighted in Red, then the corresponding sites use water above the average

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Table 5.5: Quantitative and economic water use performance results for UK butter production

Figure 5.16 and table 5.5 present results of the benchmarking exercise on water use for the production of butter in UK. It is seen that out of the 13 benchmarked sites, only one site uses water averagely, the rest use water poorly. Rates of water use in Sites 11 and 12 are so high that the validity of these entries were first verified to avoid any form of data spuriousness. However, since the data were collected from secondary sources, the collection medium was not accessible, so it was not possible to find out whether these extremely high values reflect the true status of the companies in terms of their rates of water use.

iii. Water use benchmarking for Cheese production

i-Water Benchmarking tool

Business Council for Sustainable Development United Kingdom

HERIOT WATT UNIVERSITY

BENCHMARKING RESULTS

Contact Information | Benchmarking Specifics | Data Input & Validation | **Benchmarking Results**

Benchmarking Date: 11/03/2016 13:26

Benchmarking Staff: Ikenna Ajiero

Company category: Commercial Organizatior

Industrial Sector: Manufacturing

Division: Dairies

Segment: Cheese

Company Name:

Branch/Site: Edinburgh

Company Address:

Zip/Post Code: EH14 4AS

Telephone: XXX-XXX XXXX

State: Scotland

Country: UK (United Kingdom)

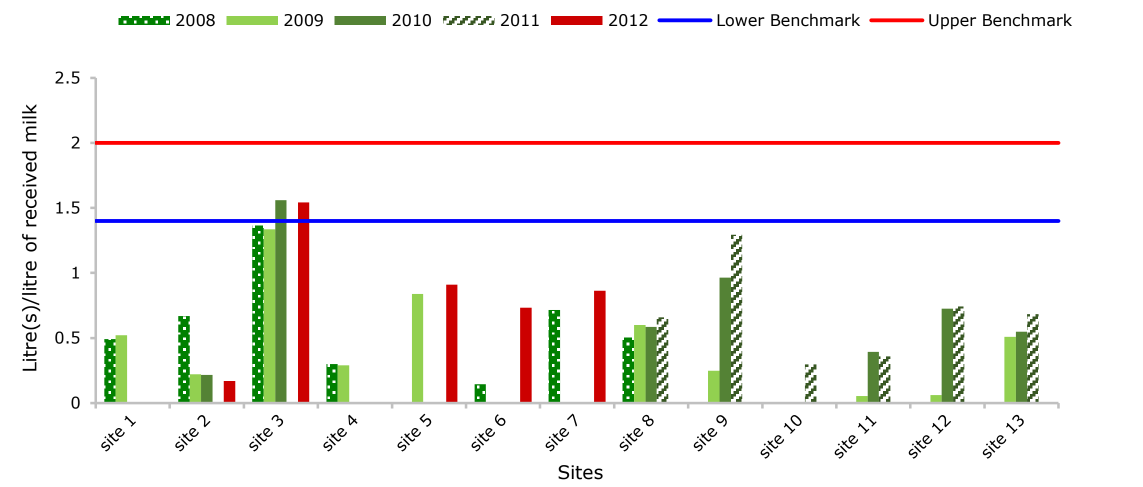
Production Process: Average consumption for entire production process

KPI: Water Use per Unit Product (Relative)

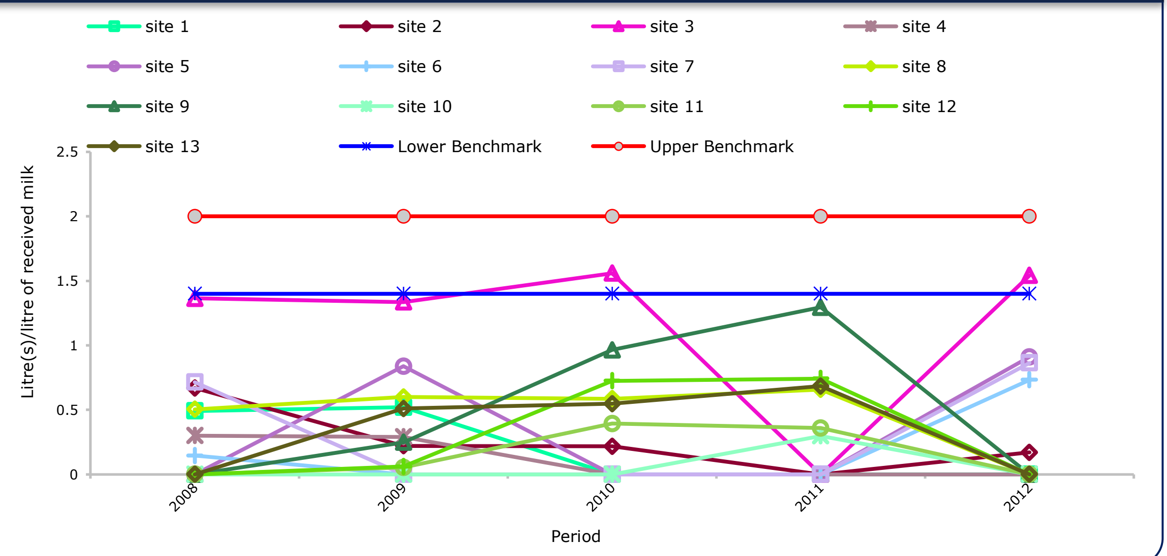
Benchmarking Unit: Litre(s)/litre of received milk

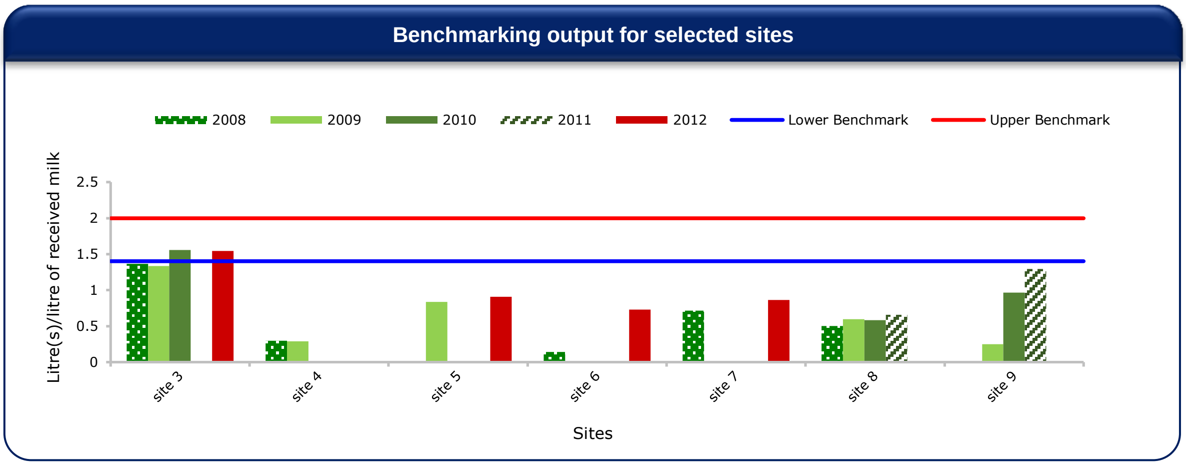
Notes

Benchmarking output for all entries



Benchmarking output for all entries





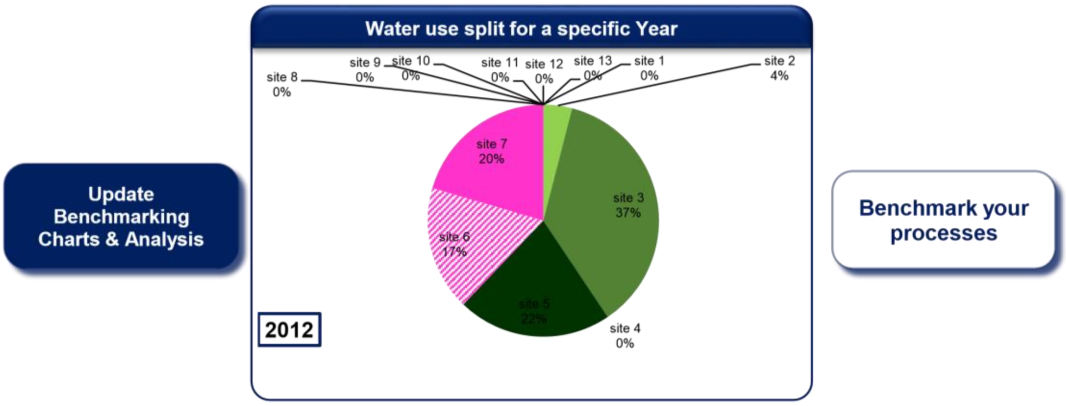


Figure 5.17: Benchmarking results of water use for UK cheese production

Site	Average water use/unit Product	Rank 1 = Highest	Benchmark (Lower)	Deviation about Benchmark	Deviation Value (%)	Water charges (£)	Wastewater charges (£)
site 1	0.51	8	1.40	-0.89	-176.7%	-£ 0.0014	-£ 0.0012
site 2	0.32	10	1.40	-1.08	-339.2%	-£ 0.0017	-£ 0.0015
site 3	1.45	1	1.40	0.05	3.5%	£ 0.0001	£ 0.0001
site 4	0.30	12	1.40	-1.10	-374.3%	-£ 0.0018	-£ 0.0015
site 5	0.87	2	1.40	-0.53	-60.2%	-£ 0.0008	-£ 0.0007
site 6	0.44	9	1.40	-0.96	-219.4%	-£ 0.0015	-£ 0.0013
site 7	0.79	4	1.40	-0.61	-77.4%	-£ 0.0010	-£ 0.0008
site 8	0.59	5	1.40	-0.81	-138.7%	-£ 0.0013	-£ 0.0011
site 9	0.84	3	1.40	-0.56	-67.5%	-£ 0.0009	-£ 0.0008
site 10	0.30	11	1.40	-1.10	-370.7%	-£ 0.0017	-£ 0.0015
site 11	0.27	13	1.40	-1.13	-422.5%	-£ 0.0018	-£ 0.0015
site 12	0.51	7	1.40	-0.89	-175.0%	-£ 0.0014	-£ 0.0012
site 13	0.58	6	1.40	-0.82	-141.2%	-£ 0.0013	-£ 0.0011

Nb. If cells in the table above are highlighted in Red, then the corresponding sites use water above the average

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Table 5.6: Quantitative and economic water use performance results for UK cheese production

Results above (Figure 5.17 and Table 5.6) show that most of the Sites in UK use water for Cheese production *"Excellently"*. It is seen from the output above that only Site 3 uses water "*Averagely*". However, looking at the trend chart for the *"Benchmarking output for all entries"*, it can be seen that water use by Site 3 was below the 1.4 litres / litre of milk processed (lower benchmark) in 2008 and 2009, then it dropped below this threshold in 2010 and rose again beyond the lower benchmark in 2011. It is therefore expedient for Site 3 to strive towards further reducing its water use below the lower benchmark in order to avoid this trend growing beyond the upper benchmark in subsequent years.

Chapter Six

6.0 Introduction

This chapter encapsulates two key sections; the first section reveals the research data analyses. Although, before the data analysis, each data is first summarized into corresponding variable types and meaningfully presented using charts or graphs. It is surmised that summarizing the research data will help inform the suitable statistical test for each dataset; whereas, charts and graphs shall assist in condensing and clearly revealing the requisite information about the data. Technically known as descriptive statistics, the principal aim of this first section is to make sense of the collected data.

The second part of this chapter is the inferential statistics segment. This segment features comprehensive analyses of the research data and interpretation of corresponding results. Being a quantitative study, the proposed research hypotheses shall be tested, and inferences will be drawn based on results of the analyses. To achieve this goal, the Minitab software (a statistical analysis program) shall be used to conduct the tests, and its outputs will be investigated for statistical relationships, differences, causations and trends. Accordingly, even as this section is set to reveal the data analyses results of this study, Minitab outputs that are very extensive shall be taken to appendices in order to keep this chapter as concise as possible.

In a nutshell, this chapter aims at succinctly presenting the performance status of the UK industrial sector in terms of the rate of water use by each considered subsector and its corresponding products / processes.

6.1 Industrial water use relative to UK's population growth over time *(Test of Hypothesis 1)*

In this section, the possibility of UK's population growth influencing the use of water for industrial purposes is explored. This has become expedient given the rapidity of technological advancement in the United Kingdom and the growing need to meet the basic and secondary needs of the nation's increasing population. However, it is noteworthy that with the growing rates of manufacturing and food industries' emigration from UK, due to the application of more stringent water and carbon regimes, and higher cost of production materials in the country, water use in the UK industrial sector is expected to be on the decline. A statistical assessment will then be carried out to establish the exact position of this condition.

For this assessment, the null hypothesis (H_0) to be tested is: There is no statistical relationship between UK's population growth and its use of water for industrial purposes; whereas, the alternative hypothesis (H_A) is: There is a statistical relationship between UK's population growth and its use of water for industrial purposes. In testing the above proposed hypothesis, two key factors help shape the appropriate statistical test to be conducted. The first is revealed in the term *"relationship"* which defines the proposition as a hypothesis of association or correlation. Also, the appropriate test is determined based on the variables that make up the hypothesis. Extracting the corresponding variables, we have:

Y (dependent/criterion variable) = Industrial water use rates (predictor variable)

X (independent/criterion variable) = UK's population growth over years (Predictor variable)

Since the data or observations were taken annually, the dataset is appropriately treated as time series data. This is contrary to cross-sectional data that are collected at same time or not taken over time in a specific order (diurnally, monthly, quarterly, annually, etc.). To this end, the considered appropriate statistical analysis method for this data type is the Time series regression. This will enable the test of possible significant relationship(s) or association(s) and interaction(s) between the key variables (water use and population), relative to the time period under consideration.

Therefore, for this analysis, water use data collected from the four constituent countries of the United Kingdom will be treated discretely, and corresponding inferences shall be drawn from each result. This is considered appropriate because data collected for this analysis did not originate from one source and the years covered by individual regions largely vary. On this note, industrial water use relative to population over time shall be compared in the following regions: England, Wales, Northern Ireland, and Scotland.

6.2 England's industrial water use relative to its population growth over time *(Test of Hypothesis 1a)*

As aforementioned, the first step to any detailed inferential analysis is the presentation and description of the data, which is known as descriptive statistics. A key aspect of the descriptive statistics is the presentation of this information graphically. Figures 6.1, 6.2 and 6.3 are charts showing England's rate of water use for manufacturing processes, electricity supply and industrial purposes (which combines the water use for manufacturing and electricity supply), against its population growth.

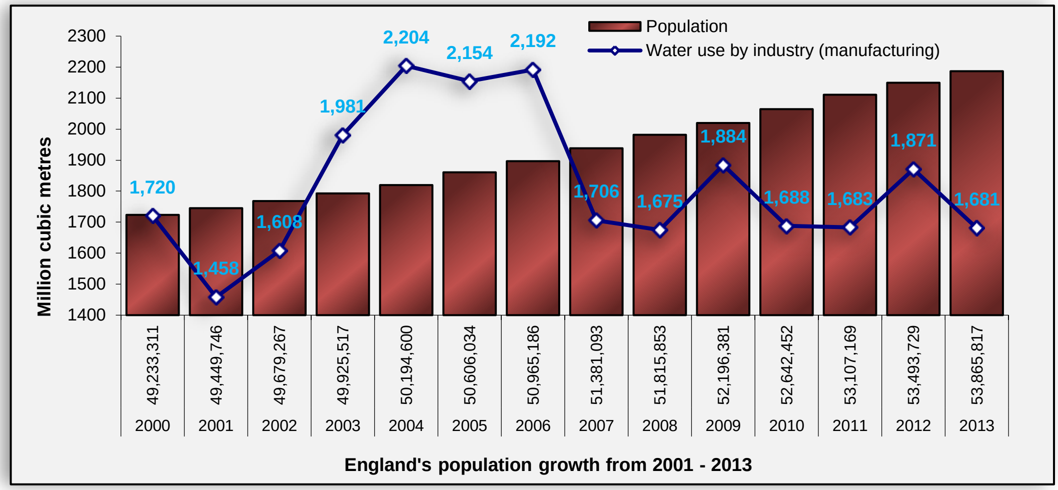

Figure 6.1: England's water use for manufacturing, relative to its population growth from 2001 to 2013

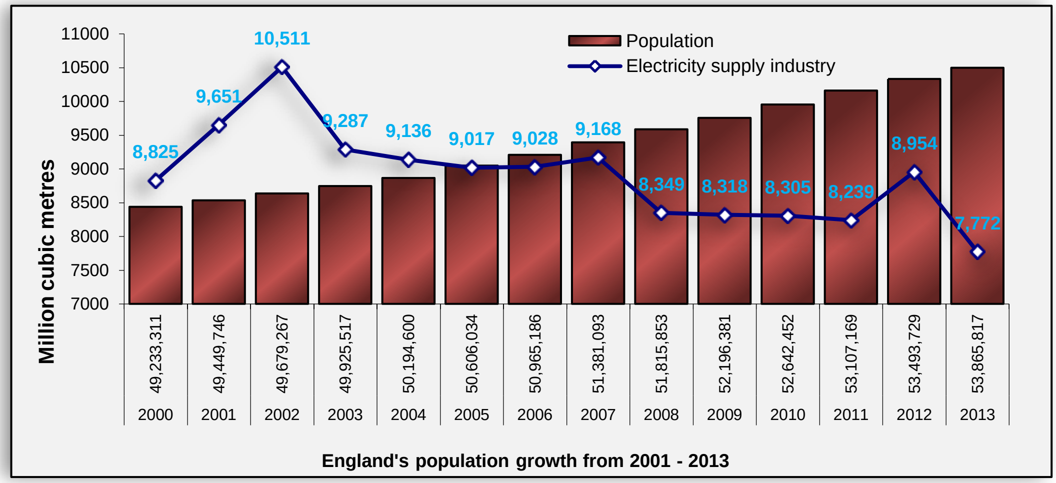

Figure 6.2: England's water use for electricity supply, relative to its population growth (2001-2013)

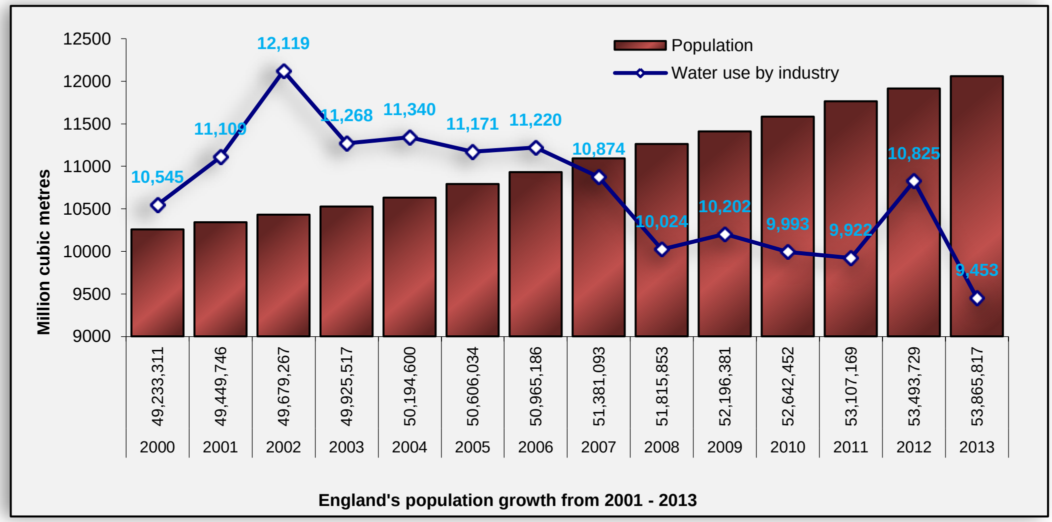

Figure 6.3: England's industrial water use relative to its population growth from 2001 to 2013

The three charts above reveal a relatively declining trend in water use against the growing population of England. To further verify this position, the data shall be statistically tested for possible significant relationship(s) between the two variable: water use and population. This process is referred to as inferential statistics.

i) The Null Hypothesis (H_0)

There is no statistical relationship between England's population growth over time and its use of water for industrial purposes

ii) The Alternative Hypothesis (H_A)

There is a statistical relationship between England's population growth over time and its use of water for industrial purposes.

iii) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.2.1 Normality of data residuals

Applying the Anderson-Darling method to carry out the normality test, the calculated P-Value was 0.506 which is greater than the 0.05 confidence level (Appendix A, subsection 8.1.1). So we reject the null hypothesis which says that the data is not normal and accept the alternative hypothesis which holds that the data is normal. On this note, we conclude that the data is fit for regression analysis.

6.2.2 Scatter and fitted line plot

A very useful way of revealing any possible relationship between two variables that are to be considered for regression analysis is to make a scatter plot and possibly fit a regression line. This approach also helps in investigating possible correlation among the variables under consideration. Using Minitab to make a scatter plot, with a regression line fitted between the data points, gives the result which is revealed as figure 6.4.

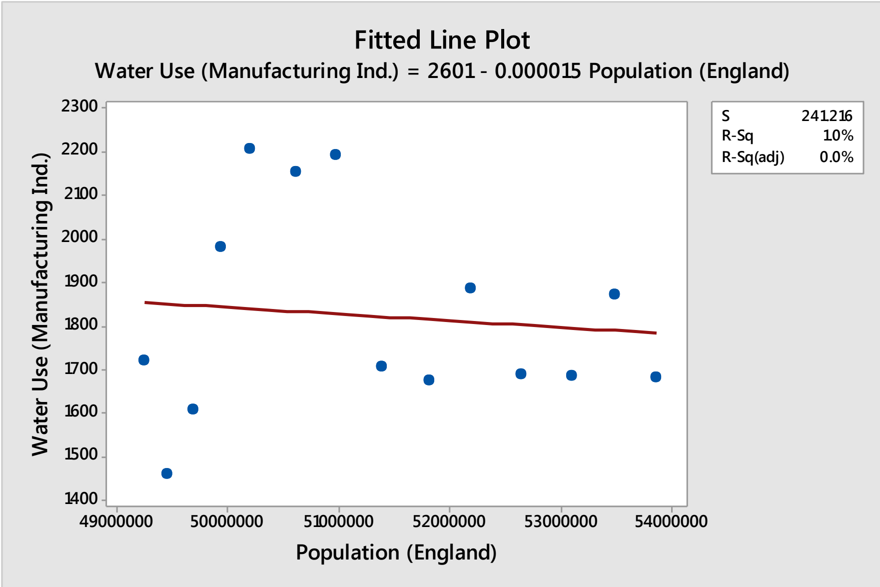

Figure 6.4: Fitted Line Plot of Water Use (Manufacturing Ind.) versus (England)

From the chart above, it clearly seen that the data points are spread apart from the line of fit; this indicates that there is a very weak relationship between the use of water for industrial purposes (manufacturing) and the population growth of England. To further explain this requires examining the R^2 value. The R^2 in this case is 1.0% which means that 1% of the water use in the manufacturing industry (the Y variable) is explained by variation (increase) in population of England over time, in a linear model. Thus, 1% of the variation in the dependent variable (Y) is explained by the regression model (line of best fit). For the R-Sq(adj) value of 0%, it implies that relative to the variation in the value of the dependent variable, 0% is as a result of the model which is actually due to change in the independent variable (X); whereas, 100% is due to some unexplained factors such as the technology in use and mode of productions, or simply put, as a result of an error.

Lastly, from the model: Water use (Manufacturing Ind.) = 2601 – 0.000015 Population (England), the line of fit intercepts the Y axis at 2601 million cubic meters, with a slope of -0.000015. This means that for every increase in the population of England by 1 person, water use by the manufacturing industry decreases by 0.000015 * 1 million cubic meters.

6.2.3 Correlation of variables

In practice, it is appropriate to confirm that there is a correlation among variables before conducting any regression analysis. This helps to advise the need to or not to continue with the regression exercise. Appendix A, subsection 8.1.2 is the result of correlation analysis for the three variables under consideration, that is, Water Use (Manufacturing Ind.), Population (England) and Year.

From the hypothesis test for correlation result gotten from the analysis conducted using Minitab (see Appendix A, subsection 8.1.2), it can be seen that the Pearson correlation (r) value for the relationship between the *"Water Use (Manufacturing)"* variable and the *"Population"* is -0.101. This indicates a weak and negative relationship. Also, the P-Value gotten is 0.908 which is far greater than the 0.05 confidence level. Thus, it is concluded that no relationship exists between the variables. Accordingly, focusing on the Water Use (Manufacturing Ind.) and the Population (England), it is also clear that with a P-Value of 0.730 which is also much greater than the significance level (α value) of 0.05, it is inferred that the relationship between the Water Use (Manufacturing Ind.) and the Population (England) is insignificant. On this note, since the major focus of this study is mainly on the effect of the population growth of England on water use by the manufacturing industry, and the result shows that there is no relationship between these key variables, we discontinue the regression analysis for the three variables.

6.3 Scotland's industrial water use relative to its population growth over time *(Test of Hypothesis 1b)*

Below are the descriptive statistics of water use by the industrial sector of Scotland, relative to its population growth over time.

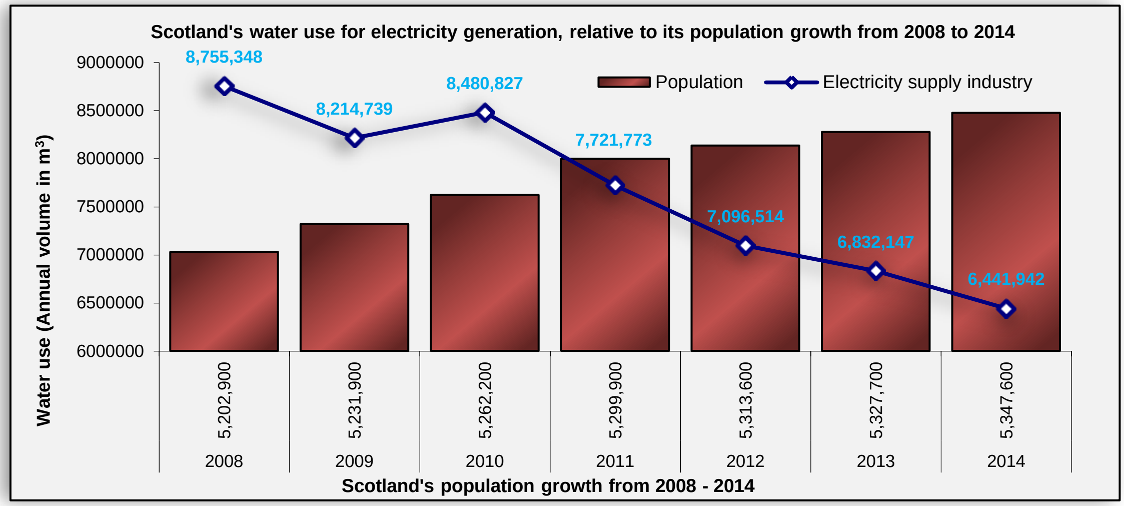

Figure 6.5: Scotland's water use for electricity generation, relative to its population growth (2008-2014)

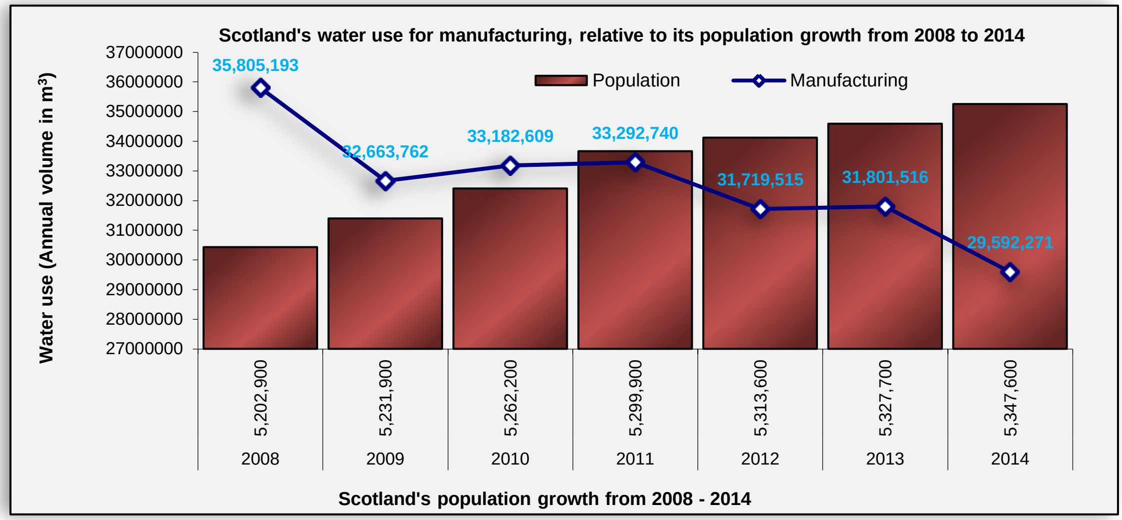

Figure 6.6: Scotland's water use for manufacturing, relative to its population growth from 2008 to 2014

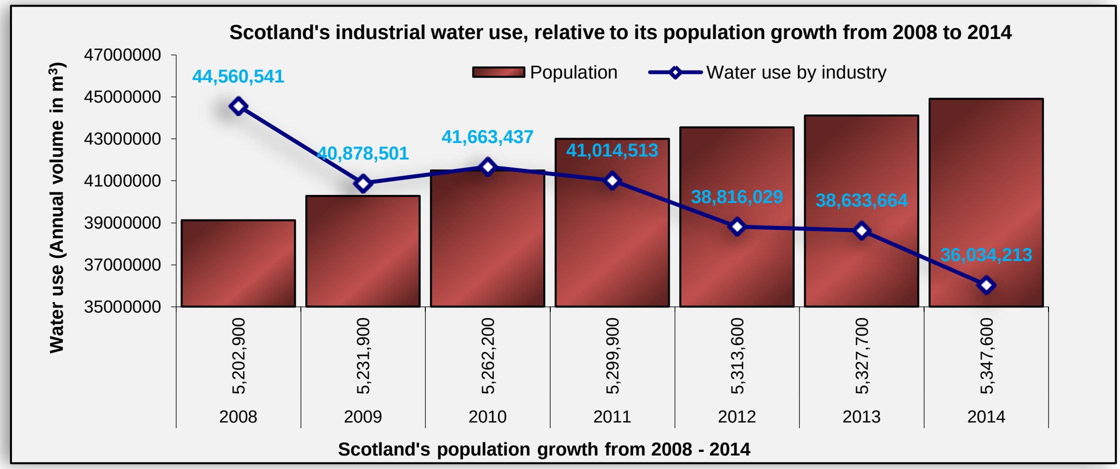

Figure 6.7: Scotland's industrial water use, relative to its population growth from 2008 to 2014

As revealed in the three charts above (figures 6.5, 6.6 and 6.7), water use for electricity generation, manufacturing and the industrial sector as a whole, show a declining trend relative to the growing population of Scotland. To further verify this position, the corresponding data shall be statistically tested for possible significant relationship(s). Below is the inferential statistics.

i) The Null Hypothesis (H_0)

There is no statistical relationship between Scotland's population growth over time and its use of water for industrial purposes

ii) The Alternative Hypothesis (H_A)

There is a statistical relationship between Scotland's population growth over time and its use of water for industrial purposes.

iii) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.3.1 Normality of data residuals (errors)

Conducting the normality test, by plotting the standardized residuals, produced a P-Value of 0.526 (see Appendix A, subsection 8.2.1) which is greater than the significance level of 0.05. So we conclude that the data to be use for this analysis is normal.

6.3.2 Scatter and fitted line plot

A careful plot of the data with a regression line fitted through the data points is revealed as figure 6.8. It can be seen from the chart that the points are meaningfully spread around the linear line of fit. Also, the R-Sq is 76.5% which implies that 76.5% of the water use in the manufacturing industry is explained by an increase in the population of Scotland with time; thus, 76.5% is as a result of the regression line. As regards the R-Sq(adj) of 71.8%, it means that 71.8% of the variation in the Y variable is due to changes in the X variable, while 28.2% is as a result of errors or some factors that are not explained by the model.

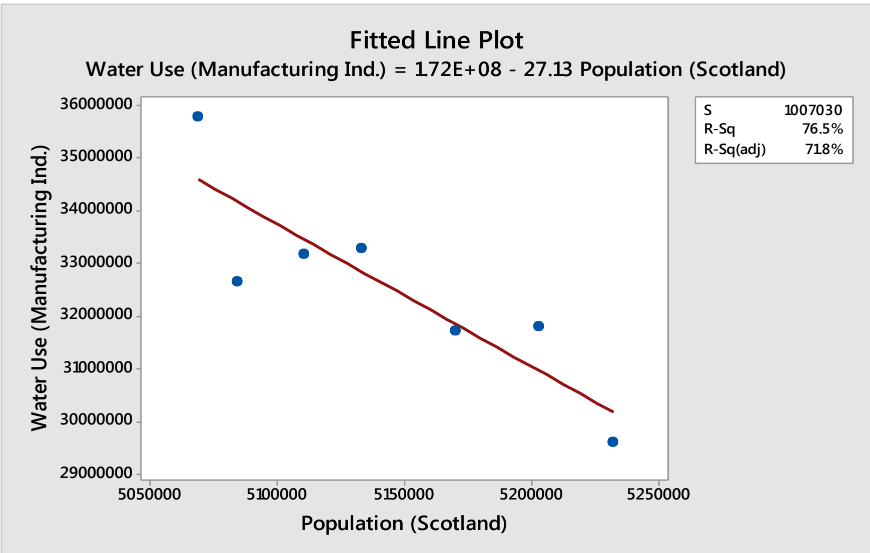

Figure 6.8: Fitted Line Plot of Water Use (Manufacturing Ind.) versus (Scotland)

Further, it is pertinent to examine the regression line or the model which is developed using the least square method. From the chart above (figure 6.8), the regression equation is: Water Use (Manufacturing Ind.) = 1.72 x 10^8 – 27.13 Population of Scotland. With a slope of -27.13, the point of intercept for this line of best fit is 1.72

x 10^8 m^3. This implies that for each increase in the population of Scotland, the volume of water used by the manufacturing industry decreases by 27.13 x Population of Scotland.

6.3.3 Interpretation of the correlation of variables output

Looking at the Pearson correlation coefficient for the Water Use (Manufacturing Ind.) and Scotland's Population growth which is: -0.874 (see Appendix A, subsection 8.2.2), a strong negative relationship can be confirmed to exist between these two variables. Accordingly, with a P-Value of 0.010 which is smaller than the significance level (α) of 0.05, it is established that there is a significant relationship between the use of water by the manufacturing industry and the population growth of Scotland. Thus, we proceed to the regression analysis.

6.3.4 Interpretation of the regression analysis output

From the Minitab output revealed in Appendix A, subsection 8.2.2, given that the calculated P-Value of 0.010 is lower than the alpha (α) value of 0.05, we reject the null hypothesis and accept the alternative hypothesis which holds that there is a statistical relationship between Scotland's population growth over time and its use of water for industrial purposes.

6.4 Wales' industrial water use relative to its population growth over time *(Test of Hypothesis 1c)*

The descriptive statistics for water use by the industrial sector of Wales relative to its population growth over time are revealed below.

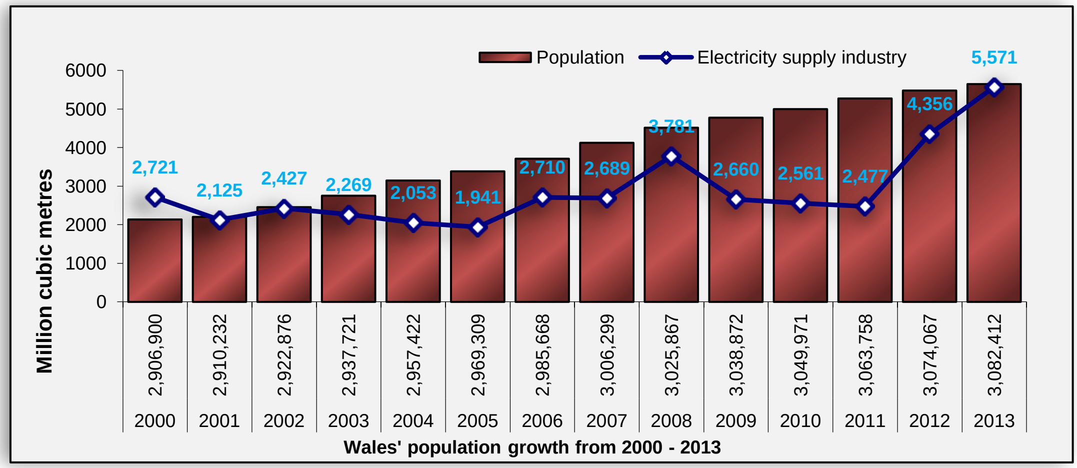

Figure 6.9: Wales' water use for electricity supply, relative to its population growth from 2001 to 2013

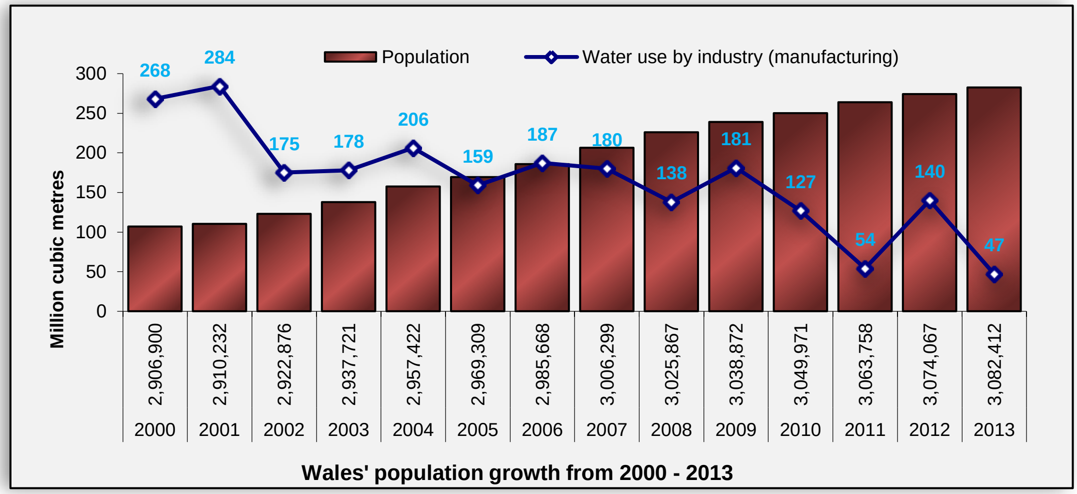

Figure 6.10: Wales' water use for manufacturing, relative to its population growth from 2000 to 2013

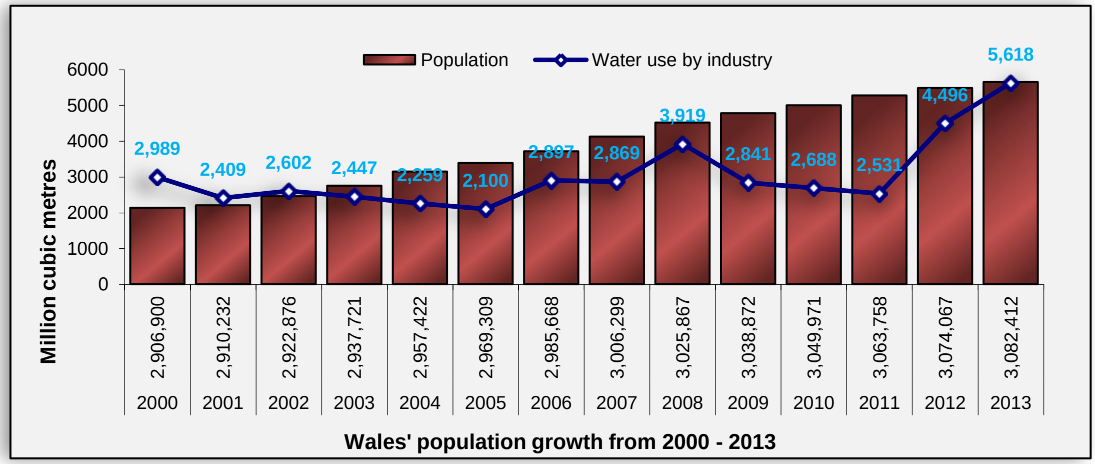

Figure 6.11: Wales' industrial water use relative to its population growth from 2001 to 2013

As observed in the three charts above (figures 6.9, 6.10 and 6.11), there is an evident declining trend in water use relative to the growing population of Wales. To verify this position statistically, a test for possible significant relationship shall be conducted. Outcome of the inferential statistics is revealed in the succeeding section.

i) The Null Hypothesis (H_0)

There is no statistical relationship between Wales' population growth over time and its use of water for industrial purposes.

ii) The Alternative Hypothesis (H_A)

There is a statistical relationship between Wales' population growth over time and its use of water for industrial purposes.

iii) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.4.1 Normality of data residuals (errors)

From the test of normality conducted, the calculated P-Value of the residual plot was 0.688 (see Appendix A, subsection 8.3.1) which is far greater than the significance level of 0.05. To this end, we infer that the data to be use for the analysis is normally distributed.

6.4.2 Scatter and fitted line plot

Output of the scatter plot of water use (Manufacturing Ind.) versus Population (Wales) and a line of best fit between the data points are revealed as figure 6.12. It is seen from the plot that the R-Sq is 68.5% which means that 68.5% of the water use in the manufacturing industry is explained by an increase in the population of Wales with time; in other words, 68.5% is as a result of the regression model.

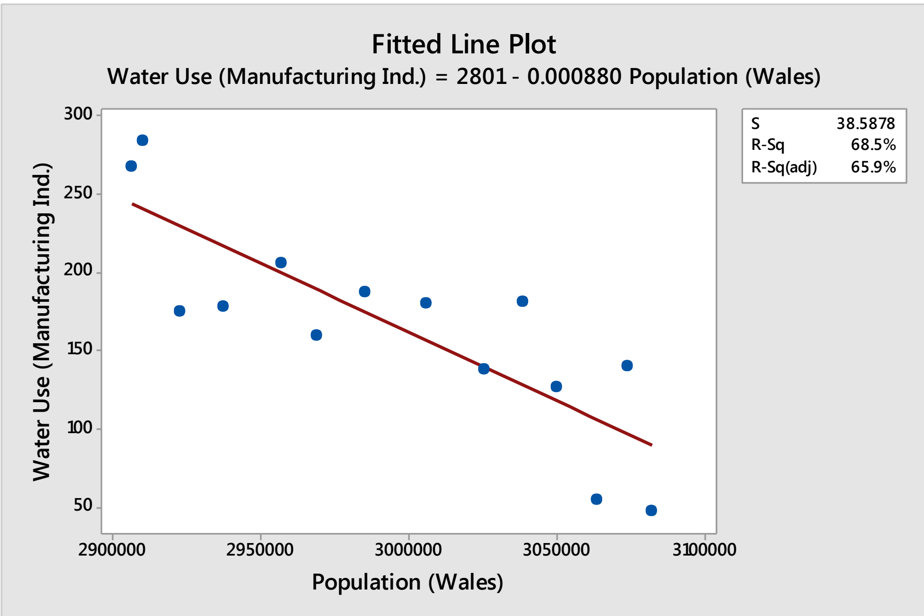

Figure 6.12: Fitted Line Plot of Water Use (Manufacturing Ind.) versus Population (Wales)

6.4.3 Interpretation of the correlation of variables output

Results of the correlation analysis shown in Appendix A (subsection 8.3.2), indicate a strong relationship between each pair of variables. It is seen that the correlation coefficient (r) of -0.828 for the Water use and Population increase and the -0.849 of Water use versus the *"Year"* provide a strong negative relationship between the variables. In contrast, the 0.996 Pearson correlation value gotten for the *"Year"* versus Population (Wales) shows an almost perfect positive relationship between the variables.

Most importantly, P-Values for each pair of variables is seen to be 0.000 which means that we reject the null hypothesis that $r = 0$, and infer that these samples where not gotten from the noise; rather, there is a statistically meaningful linear relationship between each of the paired variables considered for these exercise. Thus, regression analysis is to be conducted incorporating the three variables that currently have P-values lower than the significance level of 0.05.

6.4.4 Interpretation of regression analysis output

From the regression output gotten from Minitab (see Appendix A, subsection 8.3.3), we can see that the fitted regression model is: Water Use (Manufacturing Ind.) = 91541 + 0.00241 Population (Wales) - 49.1 Year. Further, with an r^2 of 75.99%, it can be construed that 75.99% of the variation in the dependent variable (Water use) is statistically explained by the regression module. Also, given that there are two explanatory variables *"Population"* and *"Year"* the fitted module follows the regression equation: $Y = \beta_0 + \beta_1X_1 + \beta_2X_2$; thus, it is deduced that $\beta_0 = 91541$, $\beta_1 = 0.00241$ and $\beta_2 = -49.1$. Accordingly, the corresponding test statistic for the Population (Wales) is 1.35, while that of the *"Year"* is -1.85.

As revealed in the regression analysis output, the P-Value for the overall statistical test is 0.000, which gives the conclusion that at least one of the X variables (X_1 or X_2) is significantly useful for explaining the water use in the manufacturing industry (Y variable). To confirm same, Minitab conducts an individual t-test with the null hypotheses H_0: $\beta_1 = 0$; H_0: $\beta_2 = 0$ and the alternative hypotheses being H_0: $\beta_1 \neq 0$; H_0: $\beta_2 \neq 0$.

Based on the foregoing, the P-Value of 0.204 for the Population (Wales) means that the β_1 is not significantly different from 0 when Population (Wales) is in the model. Same applies to the *"Year"* with a P-Value of 0.091 which is also greater than the α value of 0.05; thus, β_2 is also not significantly different when *"Year"* is in the model.

In a nutshell, since the overall P-Value is far less than the significance level of 0.05, we have enough statistical evidence to reject the null hypothesis and accept the alternative which is that there is a statistical relationship between Wales' population growth over time, and its use of water for industrial purposes.

6.5 Northern Ireland's industrial water use relative to its population growth over time *(Test of Hypothesis 1d)*

The descriptive statistics of water use for manufacturing processes, electricity generation and industrial products/processes in Northern Ireland, relative to its population growth over time, are revealed below.

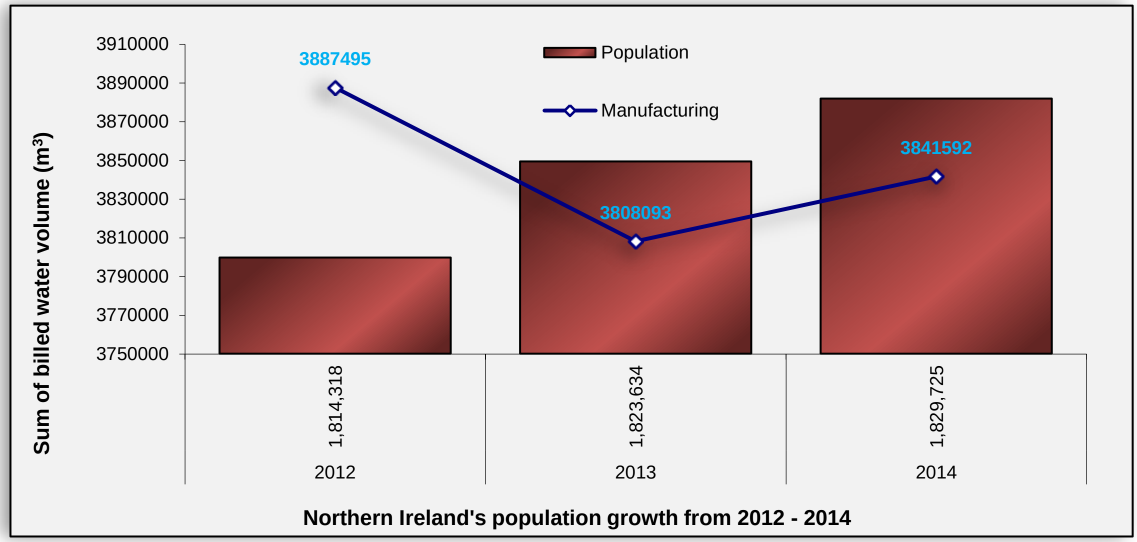

Figure 6.13: Northern Ireland's water use for manufacturing purposes relative to its population growth from 2012 to 2014

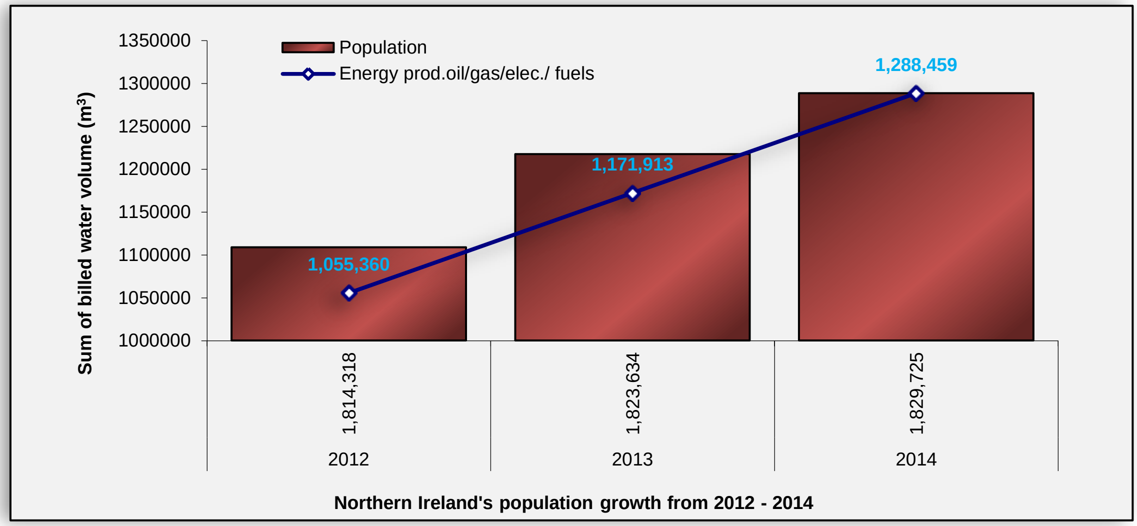

Figure 6.14: Northern Ireland's water use for electricity generation, relative to its population growth from 2012 to 2014

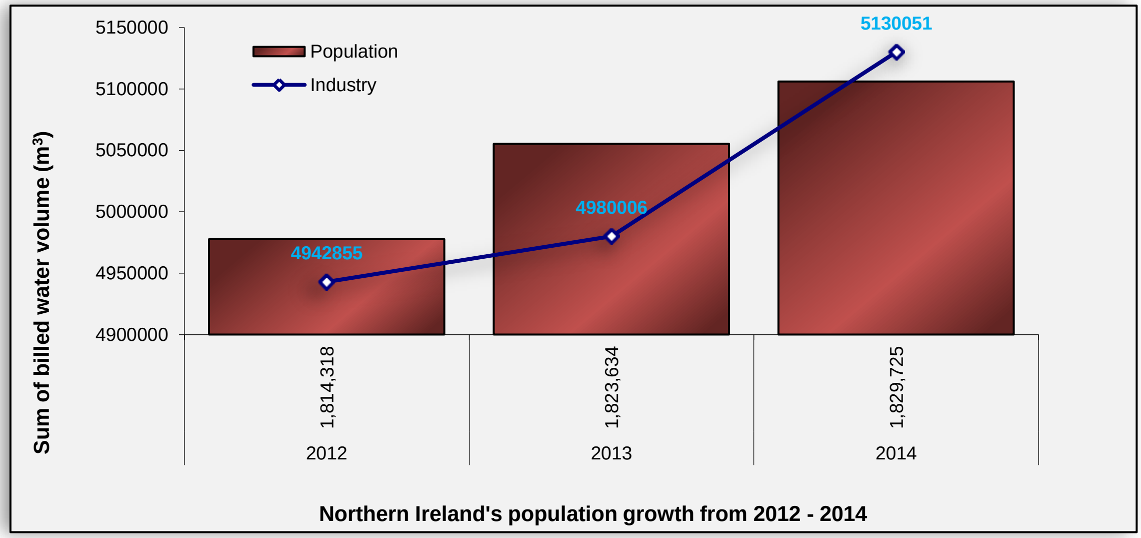

Figure 6.15: Northern Ireland's industrial water use, relative to its population growth from 2008 to 2014

Observations made on the three charts above (figures 6.13, 6.14 and 6.15) show that there is a relatively growing trend in water use by industry in relation to the population growth of Northern Ireland. To verify this position, a statistical test for possible significant relationship shall be conducted. Outcome of the inferential statistics is revealed below.

i) The Null Hypothesis (H_0)

There is no statistical relationship between Northern Ireland's population growth over time and its use of water for industrial purposes.

ii) The Alternative Hypothesis (H_A)

There is a statistical relationship between Northern Ireland's population growth over time and its use of water for industrial purposes.

iii) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.5.1 Normality of data residuals (errors)

As revealed in Appendix A, subsection 8.4.1, the P-Value of the residual plot was 0.057 which is slightly more than the significance level of 0.05, so we conclude that the data is normally distributed.

6.5.2 *Scatter and fitted line plot*

The scatter plot with a regression line fit between the data points reveals that the R-Sq is 42.8%, while the R-Sq(adj) is 0.0% (see figure 6.16). Based on the r^2 value, it means that 42.8% is explained by the model or variation in the independent variable, whereas, 67.2% is due to unexplained factors or error(s).

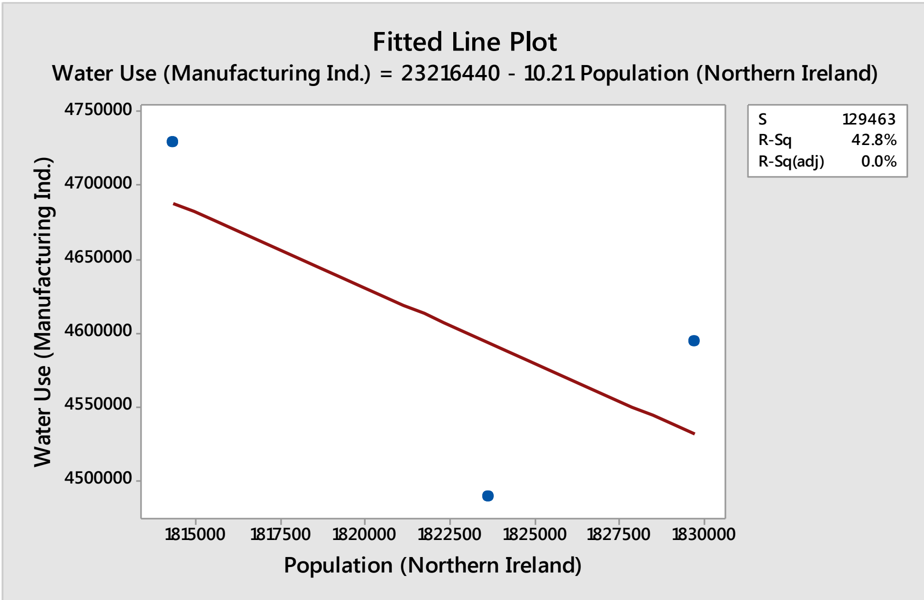

Figure 6.16: Fitted Line Plot of Water Use (Manufacturing Ind.) versus (Northern Ireland)

6.5.3 *Interpretation of the correlation of variables result*

In order to verify the need or otherwise to proceed with the regression, we conduct a hypothesis of correlation test. Results of this exercise are revealed as the output in Appendix A, subsection 8.4.2.

From the correlation results, it is seen that the P-Values for the three pairs of tested variables are all above the significance level of 0.05. This clearly indicates that there is no significant relationship between the variables under investigation; thus, the regression analysis using this data is discontinued.

6.6 Annual water use among the industrial, agricultural and domestic sectors of the UK *(Test of Hypothesis 2)*

Hypothesis 2 (H_0): There is no significant variation in annual water use among the industrial, agricultural and domestic sectors of the UK.

[Variation – difference]: Hypothesis type = Hypothesis of difference.
Y = Industrial water use rates
X_1 = Industry
X_2 = Agriculture
X_3 = Domestic

Applicable statistical method = One way ANOVA

It is apposite to state that data collected for this test did not come from a single source. In specific terms, given that the UK is made up of four constituent countries, data used for this analysis covered for regions and cannot be combined due to variations in periods covered by each dataset, and the fiscal year consideration: for instance 2001-02, 2002-03, relative to 2001, 2002, etc. Thus, test of this hypothesis will be separately conducted for England, Wales, Scotland and Northern Ireland.

6.7 Industrial, domestic and agricultural shares of annual water use in England *(Test of Hypothesis 2a)*

i) The Null Hypothesis (H_0)

There is no significant variation in annual water use among the industrial, agricultural and domestic sectors of England; or the industrial sector's water use mean (μ_1) = the agricultural sector's water use mean (μ_2) = the domestic sector's water use mean (μ_3).

ii) The Alternative Hypothesis (H_A)

There is significant variation in annual water use among the industrial, agricultural and domestic sectors of the England; or at least two of the population means differ from each other.

iii) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.7.1 Normality of data residuals (errors)

As contained in Appendix A, subsection 8.5.1, the calculated P-Value for the test of normality of data residuals is 0.15. This is greater than the significance level (α value) of 0.005, thus we reject the null hypothesis and conclude that the data distribution is normal.

6.7.2 Data summary of water use by the three major sectors of England

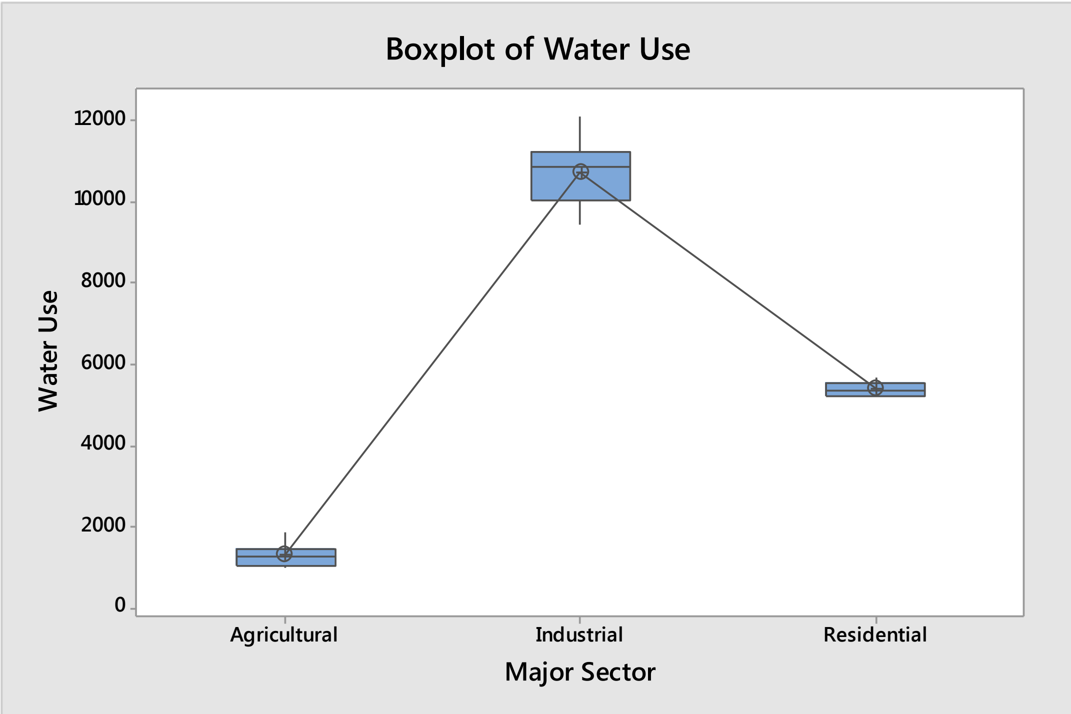

Figure 6.17: Boxplot of water use by the three major sectors (England)

Figure 6.17 is a side-by-side boxplot of water use by the three major sectors under investigation. The first observation made from the chart is that there is no outlier in any of the three plots. Also, it is clear that the mean water use by the industrial sector is comparatively higher than those of the agricultural and domestic sectors. Being a box and whiskers plot, the symmetry of each plot can be easily deduced from the chart. For the agricultural sector, with a lower quartile (Q_1) and upper quartile (Q_2) of circa 1000 and 1300 thousand cubic meters respectively, and the whisker extending far up (presence of a tail), its data distribution can be said to be skewed to the right; whereas, distribution of the industrial and residential data are considered to be relatively symmetrical. This data is further detailed to show the pattern of water use by the sectors across a 13-year period (see figure 6.18).

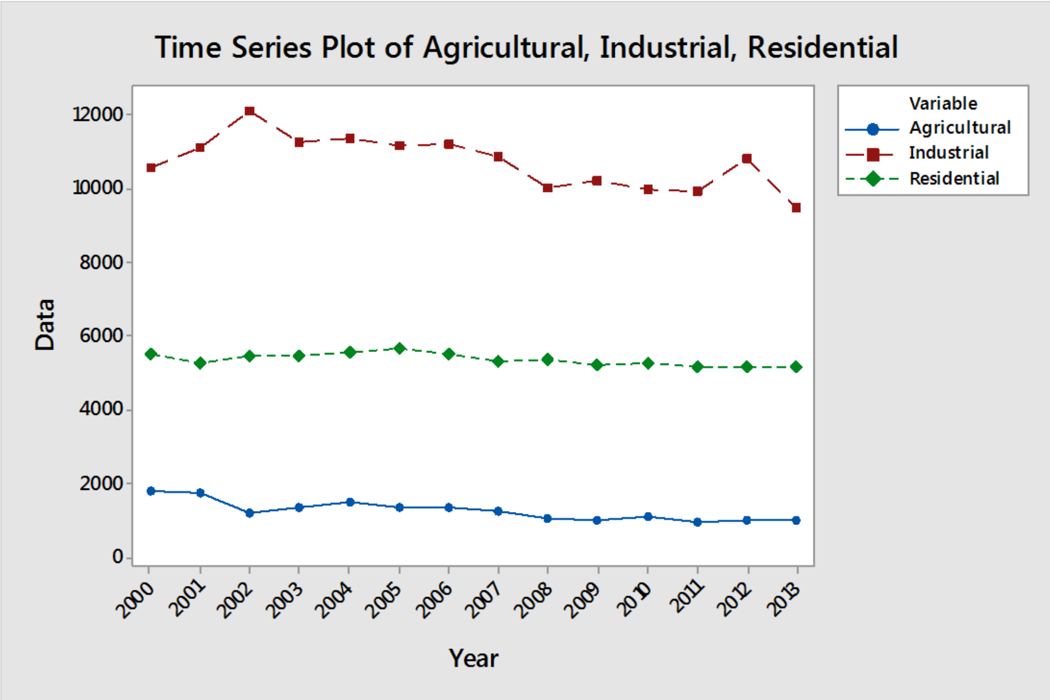

Figure 6.18: Time series plot of water use by the three major sectors (England)

The time series plot above reveals the water use trends for the agricultural, industrial and domestic sectors of England. The plot shows that water use by England's industry is the highest across the period under consideration.

6.7.3 Test of equality of variances

a) The Null Hypothesis (H_1)

Variances for water use by the industrial, agricultural and domestic sectors of the England are equal.

b) The Alternative Hypothesis (H_2)

At least two of the population variances differ from each other.

c) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.7.4 Interpretation of the test of equality of variances output

From the test conducted, the P-Value gotten is 0.000 (see Appendix A, subsection 8.5.2). Since the P-Value is less than the alpha (α) value of 0.05 we reject the null hypothesis and accept the alternative hypothesis that at least two of the variances are different.

As the variances are not equal, we use the Welch's ANOVA for the analysis rather than the traditional ANOVA which would have been used if the population variances were equal.

6.7.5 Interpretation of the Welch's analysis of variance output

From the Minitab output for the ANOVA (Appendix A, subsection 8.5.3), the F-test P-Value is 0.000 ($F_{2, 36} = 1293.59$) which is less than the alpha level of 0.05. Based on this finding, the null hypothesis is rejected, and the alternative that at least two of the population means differ from each other is accepted. Also, the R^2 value of 99.63% provides the information that 99.63% of the variation in the water use is accounted for by the major sectors. However, the major sector is made up of 3 groups or factors, and it is not possible to identify which pairs significantly vary from each other. Hence, a post hoc test is conducted. The Tukey comparison of means which is a post hoc test is carried out on the three major sectors.

6.7.6 Interpretation of post hoc test output

Results of the Tukey pairwise comparison is revealed in Appendix A, subsection 8.5.4. Firstly, as already contained in the output, *"means that do not share a letter are significantly different"*, this implies that mean values of the three groups are significantly different since each has a single letter; although the industrial sector has a significantly higher mean than the other two sectors. Also, based on the individual confidence level of 98.06%, it is inferred that for each interval we are 96.06% confident that the interval under consideration is accurate. Thus, looking at the individual pairs, for the first pair, we are 98.06% confident that the water use mean difference between the industrial and the agricultural sectors is between 8977 to 9891; this interpretation also applies to the remaining pairs.

Accordingly, it is revealed that the three variables (industrial, agricultural and residential) do not share alphabet. This suggests that their means are significantly different. Most importantly, the P-Value for each pair is 0.000 which is lower than the alpha (α) level of 0.05 and none of the intervals for each pair contains zero; so we conclude that there is strong evidence that variations in water use among the three major sectors are significant.

6.8 Industrial, domestic and agricultural shares of annual water use in Wales *(Test of Hypothesis 2b)*

i) The Null Hypothesis (H_0)

There is no significant variation in annual water use among the industrial, agricultural and domestic sectors of the Wales; ($\mu_1 = \mu_2 = \mu_3$).

ii) The Alternative Hypothesis (H_1)

At least two of the population means differ from each other.

iii) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.8.1 Normality of data residuals (errors)

Test of normality of residuals (error) of the industrial, domestic and agricultural water use data gave a P-Value of 0.291 (see Appendix A, subsection 8.6.1) which is greater than the alpha level threshold of 0.05, thus we reject the null hypothesis and conclude that the data is normally distributed.

6.8.2 Data summary of water use by the three major sectors of Wales

Inspecting the side-by-side boxplot of water use by the three major sectors which is revealed as figure 6.19, it is observed that there are two outliers in the plot. This necessitates a check of data spuriousness. A close look at the data used for this analysis reveals that in 2012, water use by the industrial sector sharply rose to 4496 million cubic meters from its value of 2531 million cubic meters in 2011; this value further increased to 5618 million cubic meters in 2013. Thus, Minitab considers these sudden peaks in water use as outliers; however, since the values were not as a result of error in measurement, the two values were retained and used for the analysis.

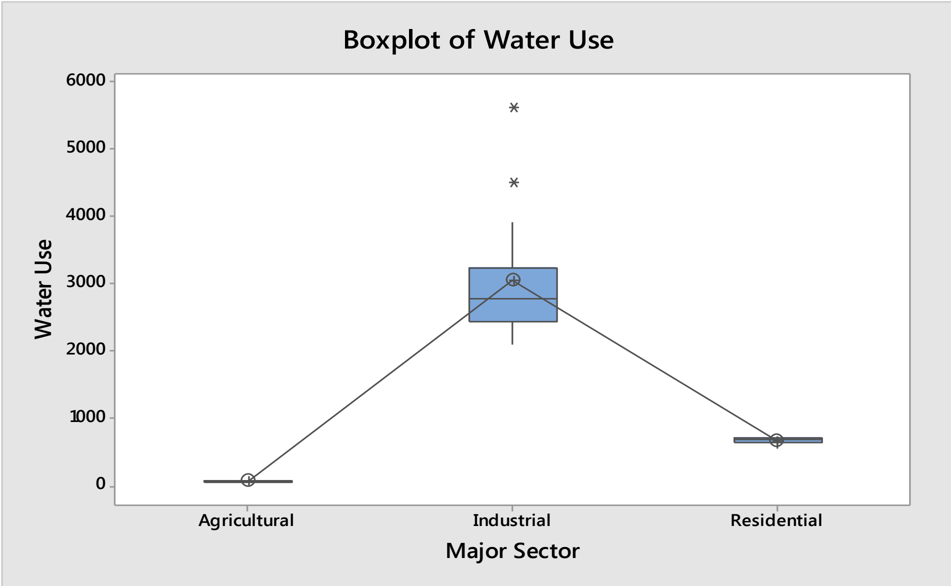

Figure 6.19: Boxplot of water use by the three major sectors (Wales)

Further interpreting the boxplot, it is evident that the mean water use by the industrial sector is relatively higher than those of the agricultural and domestic sectors. Aside the observed outliers, it can be seen that data distributions for the three sectors are comparatively symmetrical. Figure 6.20 reveals the water use trends for the agricultural, industrial and domestic sectors of Wales. It can be seen from the plot that in Wales, water use by the industrial sector remained highest throughout the period under consideration (2000 – 2013), with a very sharp surge from 2011 to 2013.

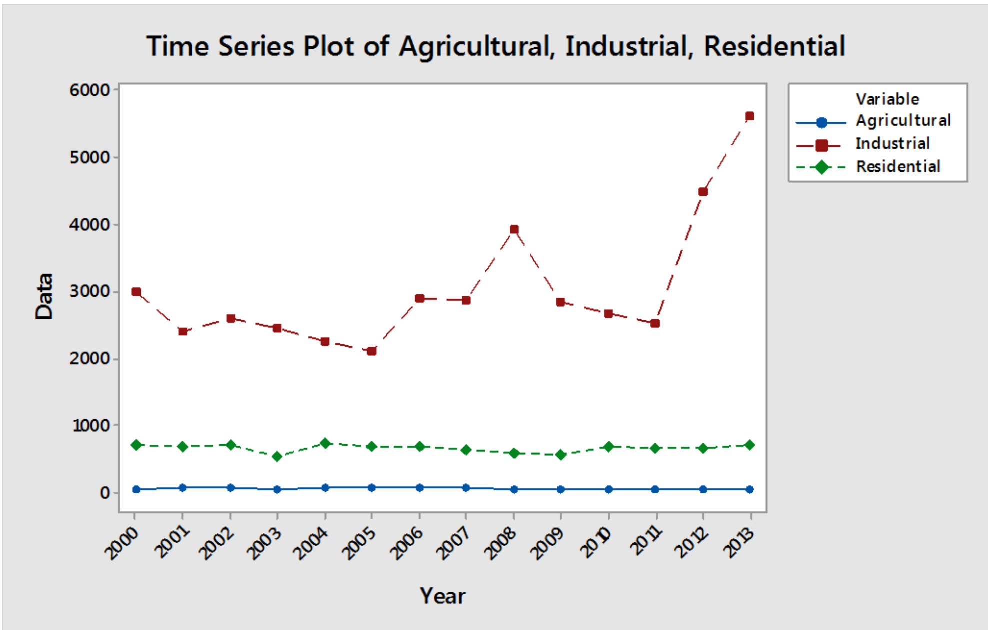

Figure 6.20: Time series plot of water use by the three major sectors (Wales)

6.8.3 Test of equality of variances

i) The Null Hypothesis (H_1)

Variances for water use by the industrial, agricultural and domestic sectors of the Wales are equal.

ii) The Alternative Hypothesis (H_2)

At least two of the population variances differ from each other.

iii) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

iv) Interpretation of output

The test of equality of variances using both the Leven's Test and Multiple comparisons, gave P-Values of 0.002 and 0.000 respectively (see Appendix A, subsection 8.6.2); these are less than the significance level of 0.05. On this note, we reject the null hypothesis and accept the alternative hypothesis that at least two of the variances are not equal. As the test of equality of variances failed, we use Welch's ANOVA to take care of this assumption of equal variances.

6.8.4 Interpretation of analysis of variance output

The Minitab output for the ANOVA revealed that $F_{2,\ 39}$ = 1101.64, and the calculated P-Value = 0.000 (see Appendix A, subsection 8.6.3) is less than the alpha level of 0.05. On this note, the null hypothesis is rejected, and the alternative that at least two of the population means differ from each other is accepted. Also, the R^2 value of 98.26% provides the information that 98.26% of the variation in the water use is explained by the major sectors.

6.8.5 Interpretation of a posteriori test outcome

As it is not possible to identify which pairs significantly vary from each other based on the general P-Value of 0.000 gotten from the analysis of variance, a Post hoc or a posterior test (Tukey pairwise precisely) is conducted to establish same (see Appendix A, subsection 8.6.4).

It is observed from results of the Tukey pairwise test that with an individual confidence level of 98.06%, we are 98.06% confident that the intervals under consideration are accurate. Then, looking at the first individual pair, we are 98.06% confident that the water use mean difference between the industrial and the agricultural sectors is between 3.6608 and 4.0659; this interpretation also applies to the remaining pairs. But most importantly, the P-Value for each pair is 0.000 which is lower than the alpha (α) level of 0.05; and looking at figure 8.9 (contained in Appendix A, subsection 8.5.2), none of the intervals for each pair contains zero; so we conclude that there is strong evidence that the variation in water use between the three major sectors is significant.

6.9 Industrial, domestic and agricultural shares of annual water use in Northern Ireland *(Test of Hypothesis 2c)*

i) The Null Hypothesis (H_0)

There is no significant variation in annual water use among the industrial, agricultural and domestic sectors of the Northern Ireland; or $\mu_1 = \mu_2 = \mu_3$.

ii) The Alternative Hypothesis (H_A)

At least two of the population means differ from each other.

iii) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.9.1 Normality of data residuals (errors)

The probability plot of the industrial, domestic and agricultural sectors' data residuals gave a P-Value of 0.161 (see Appendix A, subsection 8.7.1) which is greater than the confidence interval of 0.05; hence, we reject the null hypothesis and conclude that Northern Ireland's water use data is normally distributed.

6.9.2 Data summary of water use by the three major sectors of Northern Ireland

The side-by-side boxplot of water use by the three major sectors in Northern Ireland is presented as figure 6.21. The plot reveals no outliers and data distribution of water use by the industrial, agricultural and residential sectors can be said to relatively symmetrical. Though, the mean water use by the industrial sector is higher than those of the agricultural and domestic sectors.

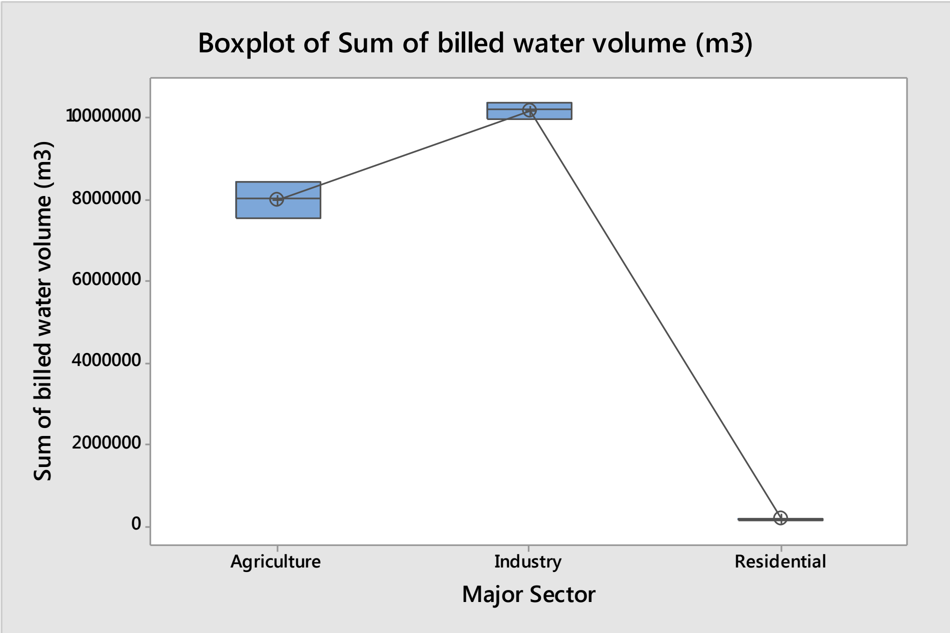

Figure 6.21: Boxplot of sum of billed water volume (m^3) (Northern Ireland)

To further understand how the agricultural, domestic and industrial sectors actually use the freshwater resource in Northern Ireland, a time series plot is provided below (Figure 6.22). The figure shows that unlike in England and Wales where agricultural water use remained the lowest for the entire assessment period; the agricultural sector of Northern Ireland is the second largest water user after the industry. Domestic water use in Northern Ireland is clearly at the lowest region of the graph.

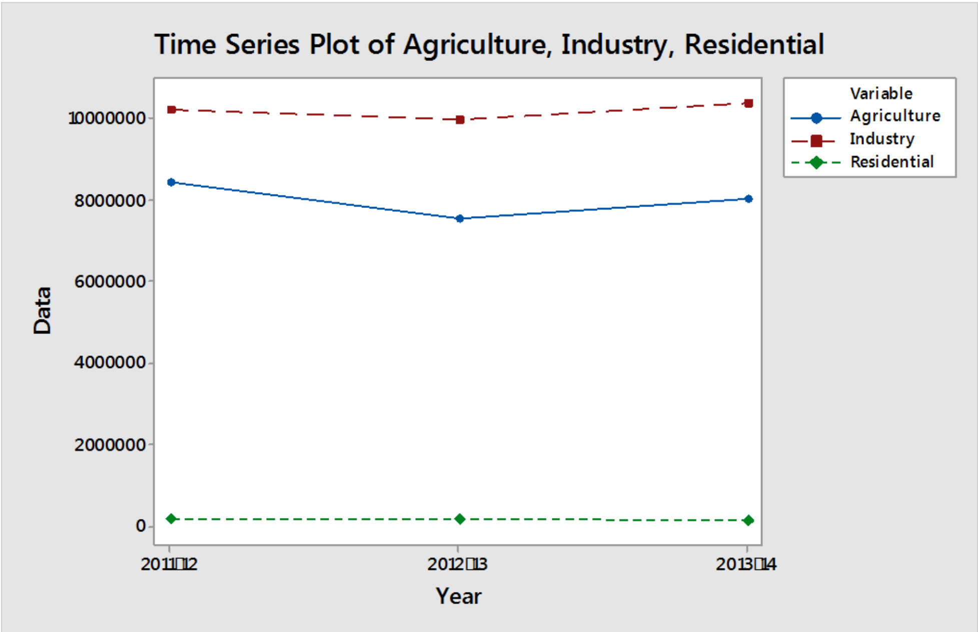

Figure 6.22: Time series plot of water use by the three major sectors of Northern Ireland

6.9.3 Test of equality of variances

i) The Null Hypothesis (H_1)

Variances of water use by the industrial, agricultural and domestic sectors of the England are equal.

ii) The Alternative Hypothesis (H_2)

At least two of the population variances differ from each other.

iii) Decision rule for statistical analysis:

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

iv) Interpretation of output

From the Bartlett's test conducted for equality of variances, a P-Value of 0.007 was gotten (see Appendix A, subsection 8.7.2). Since the P-Value is less than the alpha (α) value of 0.05 we reject the null hypothesis and accept the alternative hypothesis that at least two of the variances are different.

6.9.4 Interpretation of Analysis of variance output

With the Minitab output for the ANOVA revealing an $F_{2, 6} = 1003.65$, and a P-Value of 0.000 (see Appendix A, subsection 8.7.3) which is less than the alpha level of 0.05, we reject the null hypothesis and the alternative that at least two of the population means differ from each other is accepted. Accordingly, the R^2 value of 99.70% provides the information that 99.70% of the variation in the water use is explained by the major sectors.

6.9.5 Interpretation of the post hoc test of significance output

As the major sector is made up of 3 groups or factors, and it is not possible to identify which pairs significantly differ from each other, a post hoc test is conducted. From the post hoc result revealed in Appendix A, subsection 8.7.4, it is observed that mean values of the three groups are significantly different, since each has a single letter. It is also revealed that the industrial sector has a significantly higher mean than the other two sectors. Further, based on the individual confidence level of 97.80%, it is inferred that for each interval we are 97.80% confident that the interval under consideration is accurate. Hence, looking at the individual pairs; for the first pair, we are 95% confident that the water use mean difference between the industrial and the agricultural sectors is between 1457329 – 2900659; this interpretation also applies to the remaining pairs.

Then looking at the adjusted P-Value for each pair (which is 0.000), since 0.000 is lower than the confidence level of 0.05 and from figure 8.10 (contained in Appendix A, subsection 8.5.3), none of the intervals for each pair contains zero, we conclude that there is a strong evidence that the variation in water use between the three major sectors is significant.

6.10 Industrial, domestic and agricultural shares of annual water use in Scotland *(Test of Hypothesis 2d)*

i) The Null Hypothesis (H_0)

There is no significant variation in annual water use among the industrial, agricultural and domestic sectors of the Scotland ($\mu_1 = \mu_2 = \mu_3$).

ii) The Alternative Hypothesis (H_A)

At least two of the population means differ from each other.

iii) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.10.1 Normality of Standard residuals (errors)

Data to be used for this analysis was first tested for normality (see Appendix A, subsection 8.8.1), and it was discovered that the data was not normal as the P-Value gotten was 0.048, which is less than the alpha level of 0.05; so a transformation was carried out on the data. The transformed data then gave a P-Value of 0.935 which is higher than the significance level of 0.05; thus, we reject the null hypothesis and conclude that the data is normally distributed.

6.10.2 Data summary of water use by the three major sectors of Scotland

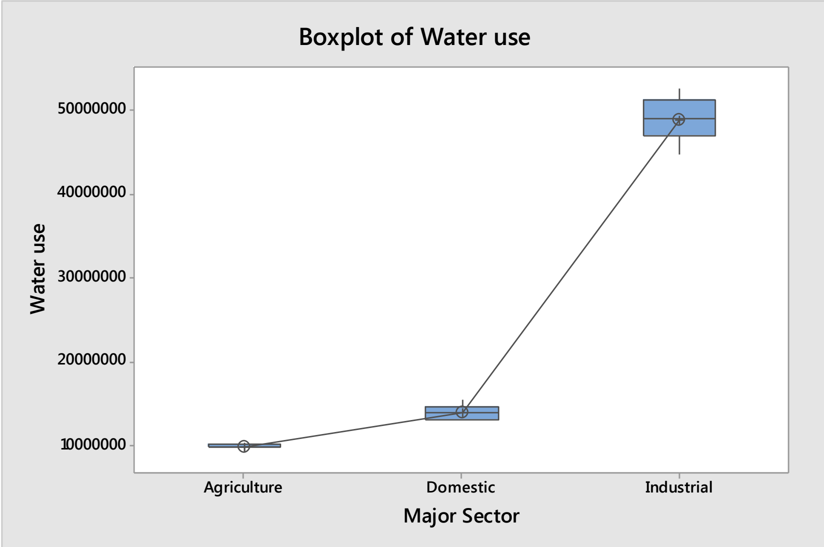

Figure 6.23: Boxplot of water use by the three major sectors (Scotland)

A first look at the above side-by-side boxplot of water use shows the marked difference in the water use means between the industrial sector and the other two sectors (see figure 6.23). Accordingly, even as the mean water use by the industrial sector is high, its data distribution is minimally skewed to the left relative to that of the domestic sector which is skewed to the right. Also, there are no outliers in the plot.

Figure 6.24 shows the water use trends for the agricultural, industrial and domestic sectors of Wales. It can be seen from the plot that in Wales, water use by the industry remained significantly highest throughout the period under consideration (2008 – 2013).

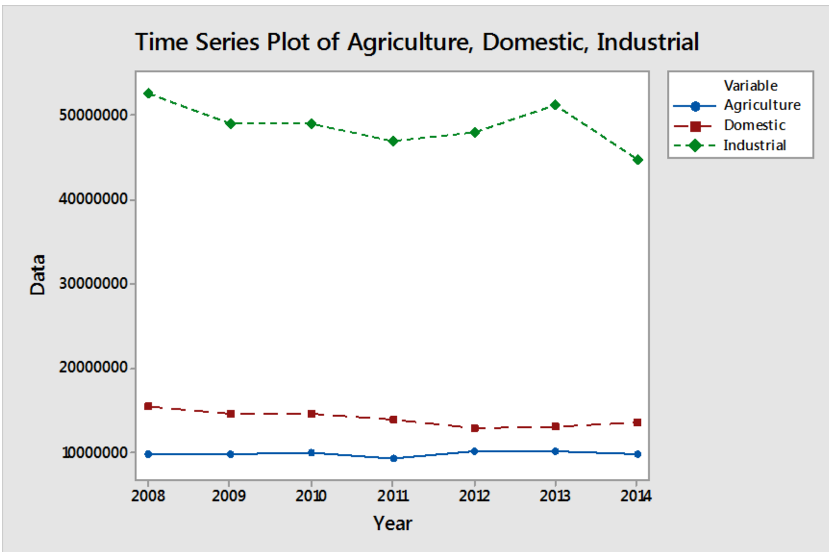

Figure 6.24: Time series plot of water use by the three major sectors (Scotland)

6.10.3 Test of equality of variances

a) The Null Hypothesis (H_1)

Variances for water use by the industrial, agricultural and domestic sectors of the Scotland are equal.

b) The Alternative Hypothesis (H_2)

At least two of the population variances differ from each other.

c) Decision rule for statistical analysis:

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.10.4 Interpretation of test of equality of variances output

Appendix A, subsection 8.8.2 provides results of the equality of variance test conducted using the Bartlett's method. The calculated P-Value is 0.104 which is greater than the significance level of 0.05. On this note, we accept the null hypothesis that variances for water use by the industrial, agricultural and domestic sectors of Scotland are equal.

Having met the assumption of normality of residuals and equality of variances, we proceed to the ANOVA for test of hypothesis 2d.

6.10.5 Interpretation of analysis of variance output

The F-value from the ANOVA is 1530.67 ($F_{2, 18}$), whereas the P-Value is 0.000 (see Appendix A, subsection 8.8.3) which is less than the alpha level of 0.05. To this end, the null hypothesis is rejected, and the alternative that at least two of the population means differ from each other is accepted.

Accordingly, the R^2 value of 99.42% provides the information that 99.42% of the variation in the water use is explained by the major sectors.

6.10.6 Interpretation of the post hoc test outcome

Given that it is not possible to identify which pairs significantly vary from each other based on the general P-Value of 0.000 gotten from the analysis of variance, a Post hoc test - Tukey pairwise comparisons, is conducted to establish same.

Observing the Tukey pairwise test result which is revealed in Appendix A, subsection 8.8.4, it is evident that based on the individual confidence level of 98.00%, we are 98.00% confident that the intervals under consideration are accurate. Then, looking at the first individual pair, we are 95% confident that the water use mean difference between the industrial and the agricultural sectors range from -0.000060 to -0.000043; this interpretation also applies to the remaining pairs. But most importantly, the P-Value for each pair is 0.000 which is lower than the alpha (α) level of 0.05 and none of the intervals for each pair contains zero; so we conclude that there is a strong evidence that the difference in water use between the pairs associated with the three major sectors is significant.

6.11 Annual water use (relative to production) by UK production (manufacturing) companies *(Test of Hypothesis 3)*

Hypothesis 3 (H_0): Rates of annual water use (relative to production) by UK production (manufacturing) companies do not significantly vary.

[Vary]: Hypothesis type = Hypothesis of difference
Y = Industrial water use rates (Interval level of measurement)
X_1 = Site 1
X_2 = Site 2
X_3 = Site 3
X_4 = Site 4 ….
X_n = Site n
Applicable statistical method = ANOVA

To conduct this statistical test, water use data were collected from several companies, covering three manufacturing sub-sectors. These companies have been designated: Site 1, 2, 3 … n, for purposes of confidentiality and anonymity. The three manufacturing sub-sectors covered in this section are Cheese, Butter and Liquid milk production.

6.12 Rates of annual water use (relative to production) by UK Liquid milk production companies *(Test of Hypothesis 3a)*

i) The Null Hypothesis (H_0)

Rates of annual water use, relative to production, by UK liquid milk production companies do not significantly vary; or $\mu_1 = \mu_2 = \mu_3 = \dots \mu_n$

ii) The Alternative Hypothesis (H_A)

At least two of the population means differ from each other.

iii) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.12.1 Normality of Standard residuals (errors)

The first normality test on the original data to be used for this analysis revealed non-normality of the data; then, using Johnson's method, the data was transformed and the probability plot for the transformed data showed that the P-Value improved from its previous value of <0.005 to 0.321 (see Appendix A, subsection 8.9.1). Thus, as 0.321 is higher than the alpha (α) value of 0.05, we conclude that the current data which is used for the analysis is normally distributed.

6.12.2 Data summary of liquid milk water use (L/L)

Figure 6.25 is a side-by-side boxplot of water use by the 27 manufacturing subsectors under investigation. From observation, the plot reveals no outliers, although each boxplot has a specific mean, median, 25^{th}, 50^{th} and 75^{th} percentile. From the plot it can be seen that Site 23 has the largest interquartile range, with a mean value of about 2 Litres of water / litre of milk produced which is higher than its median value of 1.65 Litres of water / litre of milk produced. Sites 4, 11, 17, 18 and 20 have the lowest values of mean, median, 25^{th}, 50^{th} and 75^{th} percentile. In a nutshell, Sites 20 and 26 have the highest mean value of water use for liquid milk production, while Site 11 has the lowest mean.

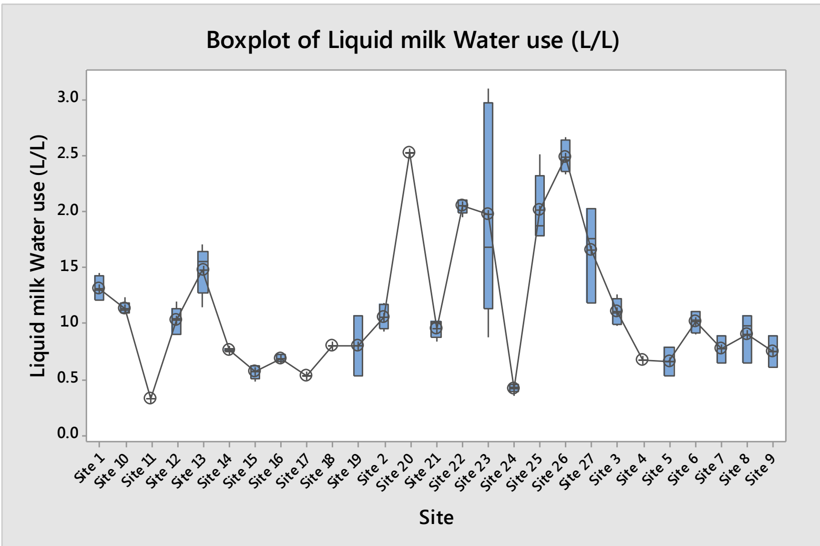

Figure 6.25: Boxplot of Liquid milk Water use (L/L) vs Site

6.12.3 Test of equality of variances

a) The Null Hypothesis (H_1)

Variances of water use by the 27 production (manufacturing) companies are equal.

b) The Alternative Hypothesis (H_2)

At least two of the population variances differ from each other.

c) Decision rule for statistical analysis:

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

d) Interpretation of output

Based on Bartlett's test conducted for equality of variances, test statistic value of 66.10 and P-Value of 0.000 were gotten (Appendix A, subsection 8.9.2). Since the P-Value is less than the alpha (α) value of 0.05, we reject the null hypothesis and accept the alternative hypothesis that at least two of the variances are different.

6.12.4 Analysis of variance

From the Minitab output in Appendix A, subsection 8.9.3, the ANOVA F-score ($F_{26, 66} = 24.96$) is found to be significant with a P-Value of 0.000 which is less than the alpha level of 0.05; hence, we reject the null hypothesis and the alternative that at least two of the population means differ from each other is accepted.

Accordingly, the R^2 value of 90.77% provides the information that 90.77% of the variation in the water use is explained by the *"Liquid milk production companies"* (manufacturing subsectors) or the model.

6.12.5 Interpretation of post hoc test of significance output

From the F-test (ANOVA) result, it is deduced that water use means of Liquid milk production companies (manufacturing subsectors) significantly vary, but we do not know which of the means actually differ from each other. So we conduct a post hoc test. Result of the Tukey comparison of water use means is revealed in Appendix A, subsection 8.9.4. The table shows that Group A contains Sites 20, 26, 22, 25, 23, 27, while Group B covers Sites 20, 23, 27, 3, etc. Also, Sites 20, 23 and 27 appear in both Group A and Group B. As contained in the Minitab output, *"Means that do not share a letter are significantly different"* and Sites 11 and 26 do not share a letter. This indicates that water use for liquid milk production by Sites 11 and 26 are statistically significant; although, Site 26 has a considerably higher mean than Site 11. We then go ahead and further observe results of the hypothesis tests for differences of means between each pair of Sites.

From the Minitab output, some of the means significantly differ. Basically, intervals that do not contain zero are considered to be statistically significant. Thus, comparing Site 10 and Site 1 with a confidence interval of -4.866 to -1.516 and an adjusted P-Value of 0.000 which is less than the alpha value of 0.05, gives the evidence that the difference between this pair is statistically significant. This applies to other pairs with adjusted P-Values that are less than 0.05. It is however worth stating that we are 95% confident that these interval are correct.

6.13 Annual water use (relative to production) by UK Cheese production companies *(Test of Hypothesis 3b)*

a) The Null Hypothesis (H_0)

Annual water use, relative to production, by UK Cheese production companies do not significantly vary; or $\mu_1 = \mu_2 = \mu_3 = \ldots \mu_n$

b) The Alternative Hypothesis (H_A)

At least two of the population means differ from each other.

c) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.13.1 Normality of data residuals (errors)

The probability plot of residuals provided a calculated P-Value of 0.504 (see Appendix A, subsection 8.10.1) which is greater than the confidence interval of 0.05; hence, we reject the null hypothesis and conclude that the data is normally distributed.

6.13.2 Data summary (UK Cheese production)

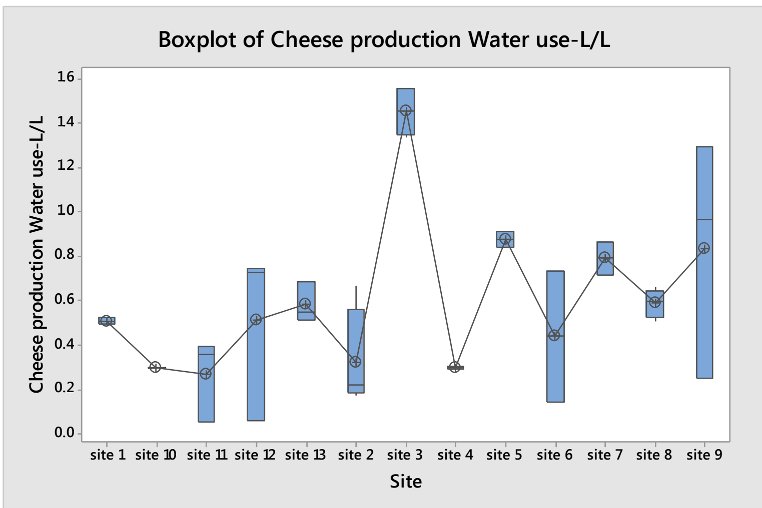

Figure 6.26: Boxplot of Cheese production water use (L/L)

Closely observing the above side-by-side boxplot of water use by the 10 manufacturing subsectors (see figure 6.26), it is clear that the data contains no outliers. From the plot, it is also deduced that Site 3 has the highest mean value of water use for Cheese production, while Site 2 has the lowest mean with distribution that is skewed to the right. Accordingly, it can be seen that Site 9 has the largest interquartile range, with a mean value of about 0.88 Litres of water / litre of Cheese produced which is higher than its median value of 0.82 Litres of water / litre of Cheese produced. Site 10 has the lowest value of mean, median, 25th, 50th and 75th percentiles.

6.13.3 Test of equality of variances

a) The Null Hypothesis (H_1)

Variances of water use by 9 production (manufacturing) companies are equal.

b) The Alternative Hypothesis (H_2)

At least two of the population variances differ from each other.

c) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

d) Interpretation of output

From the Bartlett's test of equality of variances, the test statistic value of 23.86 and P-Value of 0.013 were gotten (see Appendix A, subsection 8.10.2). Since the P-Value is less than the alpha (α) value of 0.05 we reject the null hypothesis and accept the alternative hypothesis that at least two of the variances are different.

6.13.4 Interpretation of analysis of variance output

Appendix A, subsection 8.10.3 reveals the F-test to determine the possibility of any significant variance or difference among ANY of the water use means. The calculated F-score ($F_{12,\ 22} = 5.73$) is found to be significant with a P-Value of 0.000 which is less than the alpha level of 0.05; hence, we reject the null hypothesis and the alternative that at least two of the population means differ from each other is accepted. However, as we do not know which of the means actually differ from each other, we conduct a post hoc test.

6.13.5 Interpretation of post hoc test of significance output

Results of the Tukey comparison of water use means are revealed in Appendix A, subsection 8.10.4. From the Minitab output, it is observed that Group A contains

Sites 3, 5, 9 and 7, while Group B contains Sites 5, 9, 7, 8, 13, 12, 1, 6, 2, 10, 4 and 11. Accordingly, Sites 5, 9 and 7 are found in both Group A and Group B. As stated in the Minitab output, *"Means that do not share a letter are significantly different"* and Sites 3, 8, 13, 12, 1, 6, 2, 10, 4 and 11 do not share a letter. This indicates that water use for Cheese production by Sites 3, 8, 13, 12, 1, 6, 2, 10, 4 and 11 are statistically significant; although, Site 3 has the highest mean, while Site 11 has the lowest. Further, whereas intervals that do not contain zero are considered to be statistically significant, from the analysis, only comparisons between Site 3 - Site 10, Site 3 - Site 11, Site 3 - Site 12, Site 3 - Site 13, Site 4 - Site 3, Site 6 - Site 3, Site 8 - Site 3 do not contain zero; and these have adjusted P-Values of 0.019, 0.000, 0.003, 0.007, 0.001, 0.006 and 0.003 respectively. Since the P-Values are less than the alpha (α) value of 0.05, we conclude that differences between these pairs are statistically significant.

6.14 Rates of annual water use (relative to production) by UK Butter production companies *(Test of Hypothesis 3c)*

i) The Null Hypothesis (H_0)

Rates of annual water use (relative to production) by UK Butter production companies do not significantly vary; or $\mu_1 = \mu_2 = \mu_3 = \ldots \mu_n$

ii) The Alternative Hypothesis (H_A)

At least two of the population means differ from each other.

iii) Decision rule for statistical analysis:

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.14.1 Normality of data residuals (errors)

With the original data not following the normality condition, the data was then transformed and the probability plot for the transformed data showed that the P-Value was improved from its previous value of <0.005 to 0.803 (see Appendix A, subsection 8.11.1). As 0.803 is higher than the alpha (α) value of 0.05, we conclude that the current data which is used for the analysis is normally distributed.

6.14.2 Data summary of water use for butter production

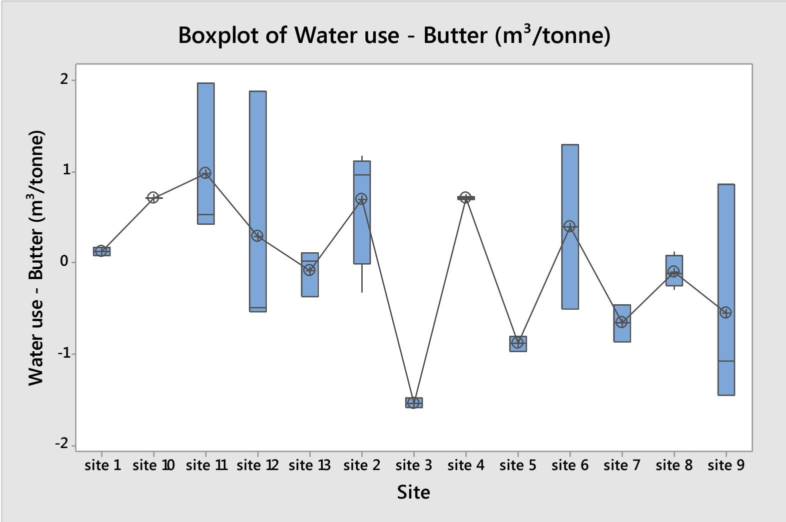

Figure 6.27: Boxplot of butter production water use (m^3 / tonne) vs Site

The above side-by-side boxplot of water use covers 13 butter producing companies (see figure 6.27). From observation, the plot reveals no outliers, although each boxplot has distinct mean, median, 25^{th}, 50^{th} and 75^{th} percentiles of data distribution. Also, from the plot, it can be seen that Site 9 and 12 have the largest interquartile ranges. Site 10 has the lowest values of 25^{th}, 50^{th} and 75^{th} percentiles; whereas, Site 2 has the highest mean value and is skewed to the left. In contrast, Site 3 has the lowest mean value.

6.14.3 Test of equality of variances

a) The Null Hypothesis (H_1)

Variances for the water use by 27 production (manufacturing) companies are equal.

b) The Alternative Hypothesis (H_2)

At least two of the population variances differ from each other.

c) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

d) Interpretation of output

Using the Bartlett's method to conduct the test for equality of variances, test statistic value of 32.04 and P-Value of 0.001 were gotten (see Appendix A, subsection 8.11.2).

Since the P-Value is less than the alpha (α) value of 0.05 we reject the null hypothesis and accept the alternative hypothesis that at least two of the variances are different.

6.14.4 Interpretation of analysis of variance output

The F-test is conducted to determine if there is significant variance or difference among or between ANY of the water use means. Appendix A, subsection 8.11.3 is the Minitab output of the F-test results which reveal that the calculated F-score ($F_{12,\ 22}$ = 3.07) is found to be significant with a P-Value of 0.011 which is less than the alpha level of 0.05. Hence, we reject the null hypothesis and the alternative that at least two of the population means differ from each other is accepted. However, as we do not know in exactness which means actually differ from each other, we conduct a post hoc test.

6.14.5 Post Hoc test of pairwise significance

Results of the Tukey comparison (Post Hoc test) of water use means are revealed are revealed in Appendix A, subsection 8.11.4. Critically observing the Minitab output, it is seen that Group A contains all Sites except Site 3; while Group B encapsulates the assessed Sites except Sites 2 and 11. Granted that Sites 11, 2 and 3 do not share a letter, we conclude that these sites are statistically significant. Site 11 has the highest mean, while Site 3 has the lowest.

Also, given that intervals that do not contain zero are inferred to be statistically significant, from the mean comparisons, only Site 3 – Site 11 interval, with an adjusted P-Value of 0.009, does not contain zero. Since the P-Value is less than the alpha (α) value of 0.05, we conclude that the difference between this pair is statistically significant.

6.15 "*Absolute*" freshwater water use by the industrial subsectors or divisions (classified according to the SIC) *(Test of Hypothesis 4)*

Hypothesis 4 (H_0): *"Absolute"* freshwater water use by the industrial subsectors or divisions (classified according to the SIC), do not statistically differ.

i) The Null Hypothesis (H_0)

"Absolute" freshwater water use by the industrial subsectors or divisions (classified according to the SIC), do not statistically differ; or $\mu_1 = \mu_2 = \mu_3 = \dots \mu_n$

ii) The Alternative Hypothesis (H_A)

At least two of the population means differ from each other.

iii) Deduction of variable types and levels of measurement

[Differ]: Hypothesis type = Hypothesis of difference
Y = Freshwater use rates (Interval level of measurement)
X_1 = Subsector 1
X_2 = Subsector 2
X_3 = Subsector 3
X_4 = Subsector 4 ….
X_n = Subsector n
Applicable statistical method = One way ANOVA

iv) Decision rule for statistical analysis:

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.15.1 Normality of data residuals (errors)

Given that the original data for this analysis did not pass the normality test, using Johnson's method, the data was transformed and probability plot for the transformed data revealed that the P-Value improved from its previous value of <0.005 to 0.321 (see Appendix A, subsection 8.11.5). As 0.321 is higher than the alpha (α) value of 0.05, we therefore conclude that the current data is normally distributed.

6.15.2 Data summary of water use by UK industrial subsectors

A critical study of the side-by-side boxplot of absolute water use by the industrial subsectors under investigation reveals that there is actually no outlier in the distribution, although each boxplot has its specific mean, median, 25^{th}, 50^{th} and 75^{th} percentiles of data distribution (see figure 6.28). From the plot it can be seen that the Soft drink sector (SIC Code 428) has the largest interquartile range and is skewed to the left. It is also observed that Pulp, paper and board sector has the lowest mean and median values, while Miscellaneous foods (SIC code 423) has the highest mean and median values of absolute water use.

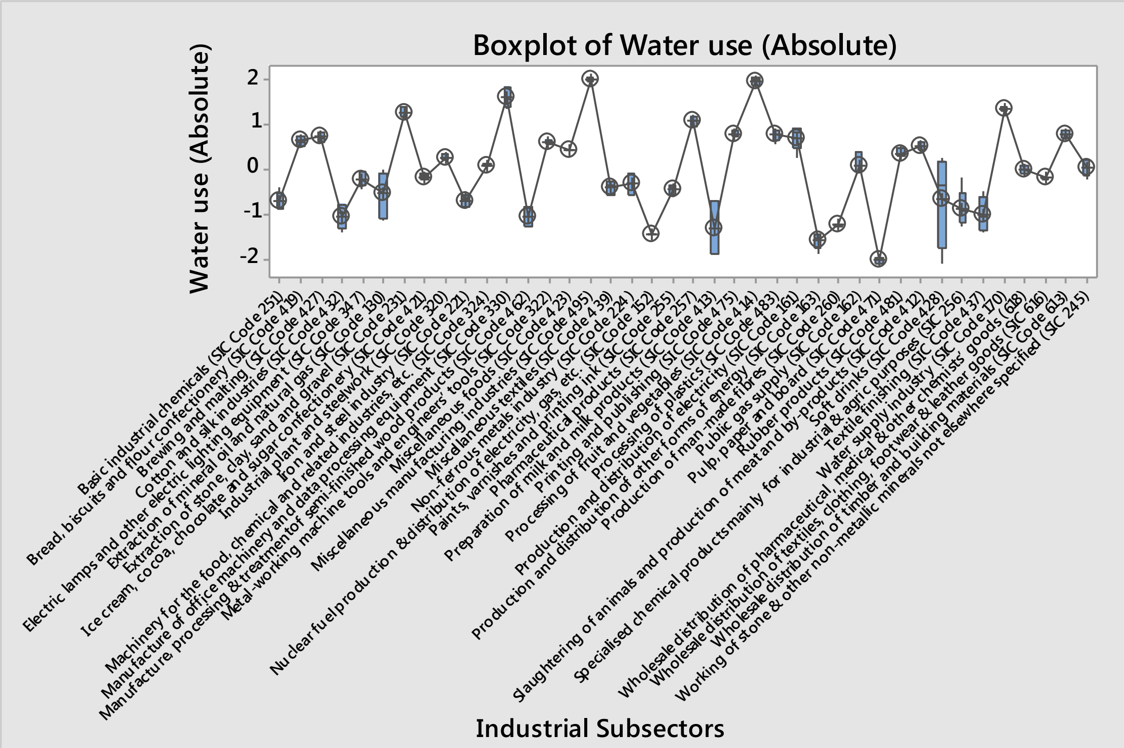

Figure 6.28: Boxplot of water use by the UK industrial subsectors

6.15.3 Test of equality of variances

i) The Null Hypothesis (H_1)

Variances for water use by the industrial subsectors under investigation are equal.

ii) The Alternative Hypothesis (H_2)

At least two of the population variances differ from each other.

iii) Decision rule for statistical analysis:

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

iv) Interpretation of output

Studying the output in Appendix A, subsection 8.11.6, which reveals the Bartlett's test for equality of variances, we observe that the test statistic value of 566.35 and P-Value of 0.000 were gotten. Since the P-Value is less than the alpha (α) value of 0.05 we reject the null hypothesis and accept the alternative hypothesis that at least two of the variances are different.

6.15.4 Interpretation of analysis of variance output

Appendix A, subsection 8.11.7 is the Minitab output of an F-test to determine if there is significant variance among any of the water use means. The calculated F-score

($F_{39, 125}$ = 55.09) is found to be significant with a P-Value of 0.000 which is less than the alpha level of 0.05; hence, we reject the null hypothesis and the alternative that at least two of the population means differ from each other is accepted. However, as we do not know which of the means actually differ from each other, we conduct a post hoc test.

6.15.5 Interpretation of post hoc test output

From the Minitab output in Appendix A, subsection 8.11.8, it is observed that Group A contains four industrial subsectors, *inter alia*: Miscellaneous manufacturing industries (SIC Code 495), Processing of fruit and vegetables (SIC Code 414), Manufacture of office machinery and data processing equipment (SIC Code 330), and Water supply industry (SIC Code 170); whereas, Group B comprises of Miscellaneous manufacturing industries (SIC Code 495), Manufacture of office machinery and data processing equipment (SIC Code 330), Water supply industry (SIC Code 170) and Extraction of stone, clay, sand and gravel (SIC Code 231). Also, industrial subsectors Miscellaneous manufacturing industries (SIC Code 495), Manufacture of office machinery and data processing equipment (SIC Code 330) and Water supply industry (SIC Code 170) are enclosed in both Group A and Group B.

Further, as contained in the Minitab output, *"Means that do not share a letter are significantly different"* based on this position, only industrial subsectors Processing of fruit and vegetables (SIC Code 414), and Pulp, paper and board (SIC Code 471) do not share a letter. Thus, we conclude that water use for Processing of fruits and vegetables (SIC Code 414), and Pulp, paper and board (SIC Code 471) are statistically significant; although, Processing of fruits and vegetables (SIC Code 414) has a higher mean than Pulp, paper and board (SIC Code 471).

6.16 Water use by major water intensive products of the UK industrial sector, over time *(Test of Hypothesis 5).*

i) The Null Hypothesis (H_0)

There is a growing trend in water use by major water intensive product of the UK industrial sector, over time.

ii) The Alternative Hypothesis (H_A)

There is a declining trend in water use by major intensive products of the UK industrial sector, over time; or water use by major water intensive products neither increases nor decreases over years.

iii) Deduction of variable types and levels of measurement

[Overtime]: Time series.
Hypothesis type = Hypothesis of association or correlation.
Y = Industrial water use rates (Interval level of measurement)
X_1 = Chemicals (Nominal level of measurement)
X_2 = Food and beverage (Nominal level of measurement)
X_3 = Metals (Nominal level of measurement)
X_4 = Pulp and paper (Nominal level of measurement)
Applicable statistical method = Trend analysis

iv) Decision rule for statistical analysis:

Reject the null hypothesis if the fitted model for each major intensive industrial product shows a declining trend in water use

6.17 Water use by main water intensive industrial products in Scotland

6.17.1 Data summary (1) of water use by main water intensive industrial products in Scotland

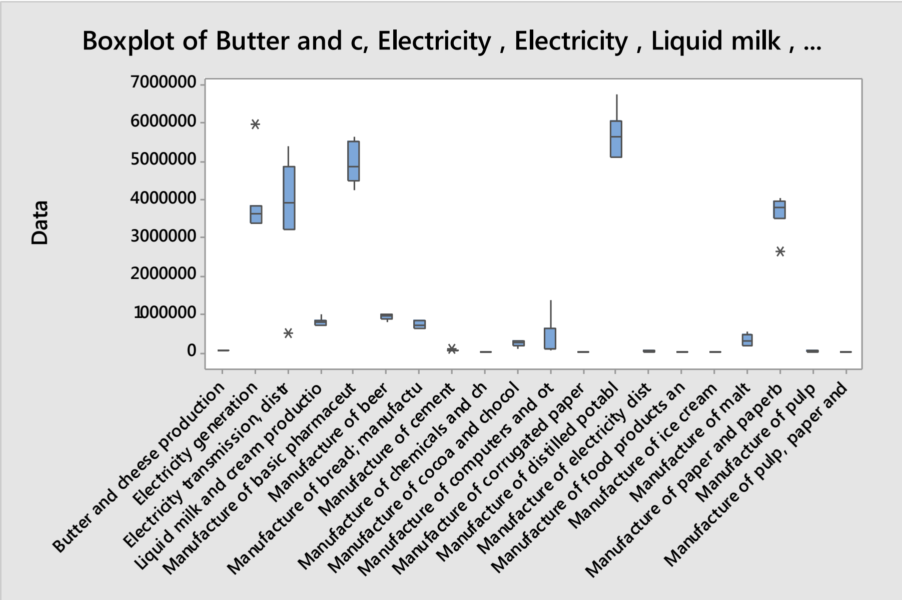

Figure 6.29: Boxplot of water use by main water intensive industrial products in Scotland

Figure 6.29 is a side-by-side boxplot of water use by the most water intensive industrial products in Scotland. From observation, the plot reveals three outliers, the first is seen in the boxplot of electricity generation; the second applies to the electricity transmission and supply, while the third is found in the manufacture of pulp, paper and cardboards. Coincidentally as can be seen in the chart, these five products / processes significantly use water more than other sectors. The data distribution of the electricity transmission and supply, manufacture of computers and other information processing equipment, and manufacture of distilled potable water are skewed to the right, while the mean water value of the electricity generation remains the highest.

6.17.2 Data summary (2) of water use by main water intensive industrial products in Scotland

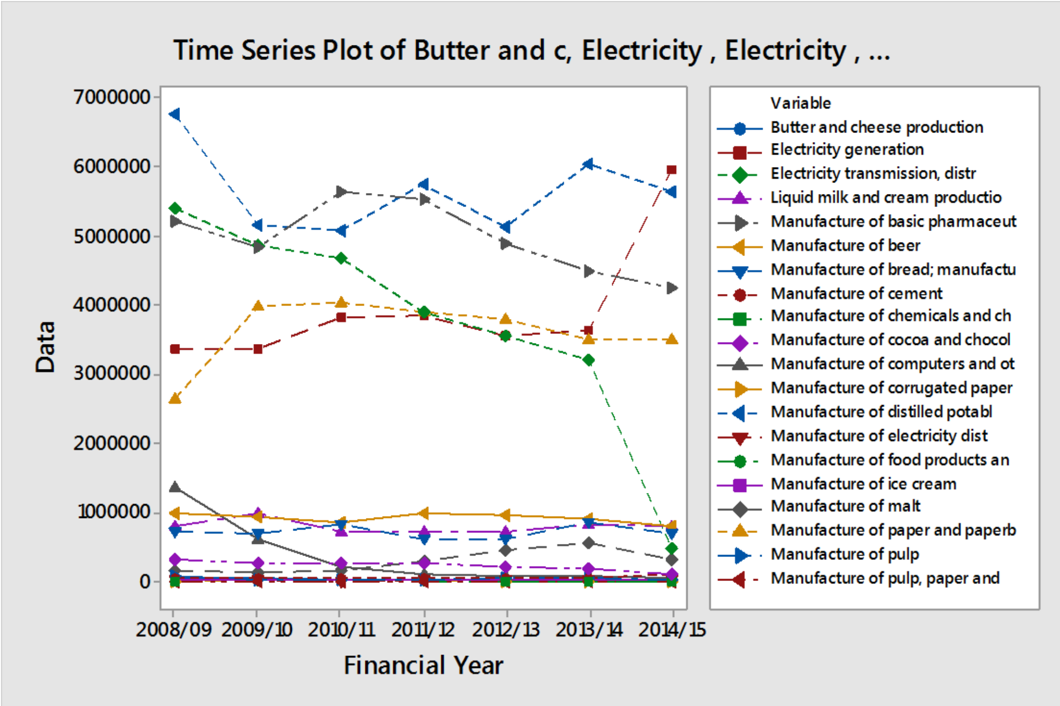

Figure 6.30: Time series plot of major water intensive industrial products in Scotland

Figure 6.30 is a time series plot of water use trend in Scotland, over years. It is observed that though the higher water using products have trends that are relatively undulating when compared with trends of the less water using products; however, water use trends by electricity generation exhibits a growing trend, while other products such as trend line for electricity distribution is clearly declining with time.

In a nutshell, it is seen from the plot that water use for manufacture of distilled potable water has been highest in Scotland for the period under investigation. To fully understand these patterns, a trend analysis is conducted on each water intensive product. Five of these highest water users have been selected for the trend analysis.

6.17.3 Trend analysis of water use for manufacture of distilled potable water

Hypothesis (H_0): There is a growing trend in water use for manufacture of distilled potable water in Scotland, over time

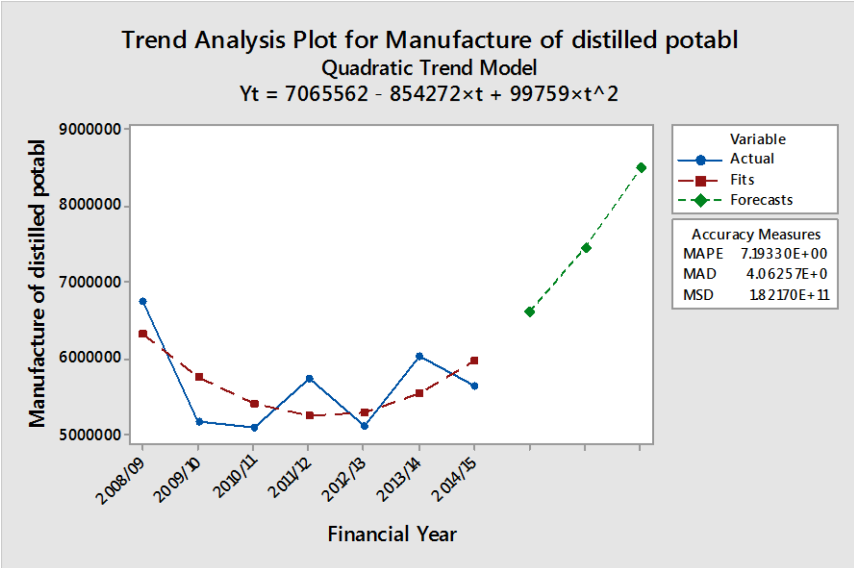

Figure 6.31: Trend analysis plot of water use for manufacture of distilled potable water

The plot above (figure 6.31) summarizes the result of the trend analysis conducted on water use for manufacture of distilled potable water. The blue line is the time series plot of the actual data, the green line is the forecast model and the red line is the fitted model drawn using the Quadratic Trend Model: Y_t = 7065562 - 854272×t + 99759×t^^{2}. Suffice it that the choice of the model: quadratic, linear or exponential is informed by the MAPE, MAD and MSD values. As noted by Minitab (2015a), being measures of accuracy, *"for all three measures, smaller values usually indicate a better fitting model"*; thus, the trend analysis was conducted severally, and the model with the smallest MAPE, MAD and MSD values was chosen as the appropriate trend analysis plot for the dataset. The MAPE denotes Mean Absolute Percentage Error and is mathematically represented by:

$$\mathrm{MAPE} = \frac{\Sigma\left|(y_t - \hat{y}_t)/y_t\right|}{n} \times 100 \qquad (y_t \neq 0)$$

MAD represents Mean Absolute Deviation, and the formula is:

$$\mathrm{MAD} = \frac{\sum_{t=1}^{n} \left|y_t - \hat{y}_t\right|}{n}$$

While, MSD stands for Mean Squared Deviation, calculated using:

$$\mathrm{MSD} = \frac{\sum_{t=1}^{n} \left|y_t - \hat{y}_t\right|^2}{n}$$

; Where y_t represents the actual data value, $\hat{y}_t$ stands for the forecast values, and n is the number of forecasts (Minitab 2015a).

As it is evident that the fitted and forecast models all show a growing trend in water use for manufacture of distilled potable water, we reject the null hypothesis that there is a growing trend in water use for manufacture of distilled potable water in Scotland, over time and accept the alternative.

6.17.4 Trend analysis of water use for Manufacture of basic pharmaceutical

Hypothesis (H_0): There is a growing trend in water use for Manufacture of basic pharmaceutical in Scotland, over time.

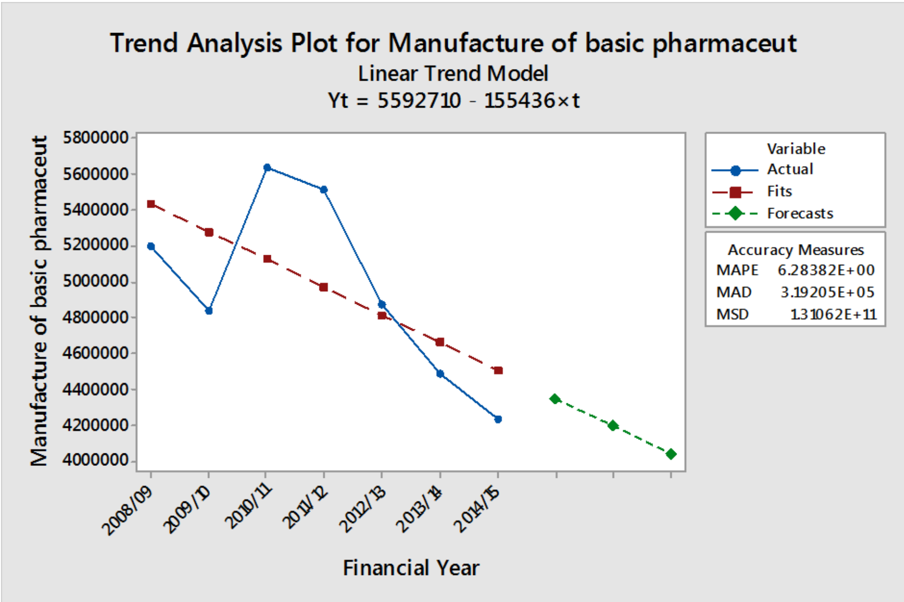

Figure 6.32: Trend analysis plot of water use for manufacture of basic pharmaceuticals

From the Minitab output presented above (figure 6.32), it is observed that a linear trend model was used relative to the quadratic or exponential models, given that the linear trend model gave the lowest MAPE, MAD and MSD. Also the plot of water use for manufacture of basic pharmaceutical shows a general downward trend with a seasonal pattern which is not very consistent with the fitted and forecast model. However, since the data plot, fit and forecast generally show a declining trend in water use, we reject the null hypothesis that there is a growing trend in water use for manufacture of basic pharmaceuticals in Scotland over time and accept the alternative that the trend is rather declining.

6.17.5 Trend analysis of water use for electricity generation

Hypothesis (H_0): There is a growing trend in water use for electricity generation in Scotland over time.

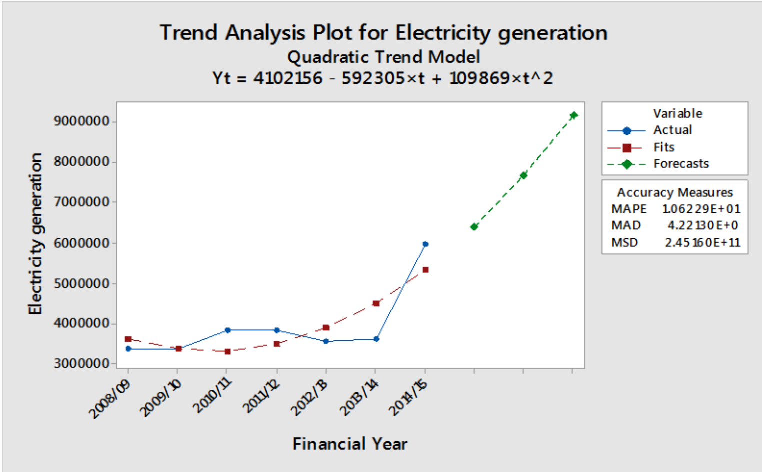

Figure 6.33: Trend analysis plot of water use for electricity generation

It is observed from the Minitab trend analysis for electricity generation that the quadratic trend equation was used to construct the fitted model (see figure 6.33). It is also evident from the actual data plot, fits and forecasts that water use for electricity generation shows a growing trend with a seasonal pattern which is relatively consistent with the fitted and forecast model. As the chart generally shows a growing trend in water use, we accept the null hypothesis that there is a growing trend in water use for electricity generation in Scotland, over time, and reject the alternative.

6.17.6 Trend analysis of water use for electricity transmission, distribution & supply

Hypothesis (H_0): There is a growing trend in water use for electricity transmission, distribution and supply in Scotland, over time.

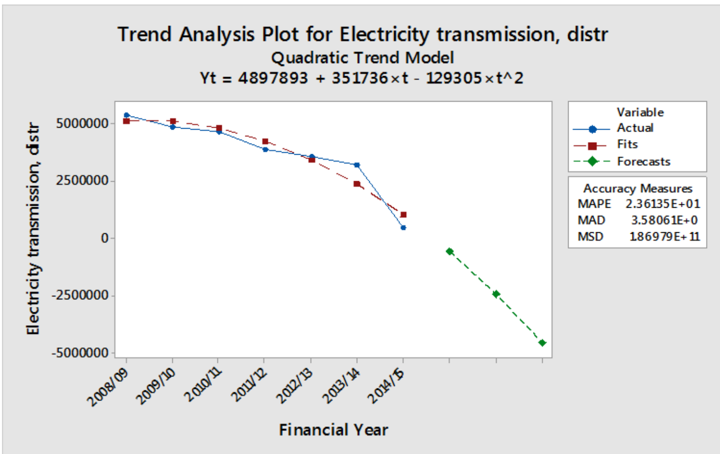

Figure 6.34: Trend analysis plot of water use for electricity transmission, distribution & supply

Figure 6.34 (above) reveals a trend analysis plot for electricity transmission, distribution and supply. Observing the actual data plot, fits and forecasts, we see that water use for electricity generation shows a declining trend with a seasonal pattern which is almost parallel to the fitted and forecast model. As the result of the trend analysis generally shows a declining trend in water use, we reject the null hypothesis that there is a growing trend in water use for electricity transmission, distribution and supply and accept the alternative which upholds that the trend is rather declining.

6.17.7 Trend analysis of water use for manufacture of beer

Hypothesis (H_0): There is a growing trend in water use for the manufacture of beer in Scotland, over time.

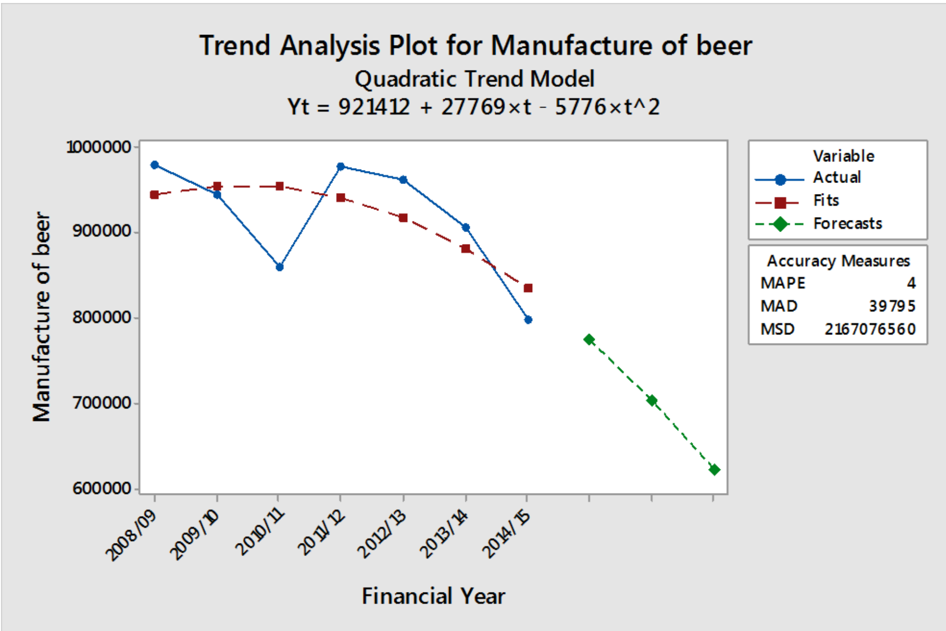

Figure 6.35: Trend analysis plot of water use for manufacture of beer

The above figure is the trend analysis result of water use for the manufacture of beer in Scotland (that is, figure 6.35). Looking at the actual data plot, fits and forecasts, we can infer that water use for manufacture of beer shows a declining trend with a seasonal pattern which is relatively consistent with the fitted and forecast model. As the result of the trend analysis generally depicts a declining trend in water use, we reject the null hypothesis that there is a growing trend in water use for the manufacture of beer and accept the alternative.

6.18 Water use by main water intensive industrial products in England and Wales

6.18.1 Data summary of water use by major water intensive industrial products in England and Wales

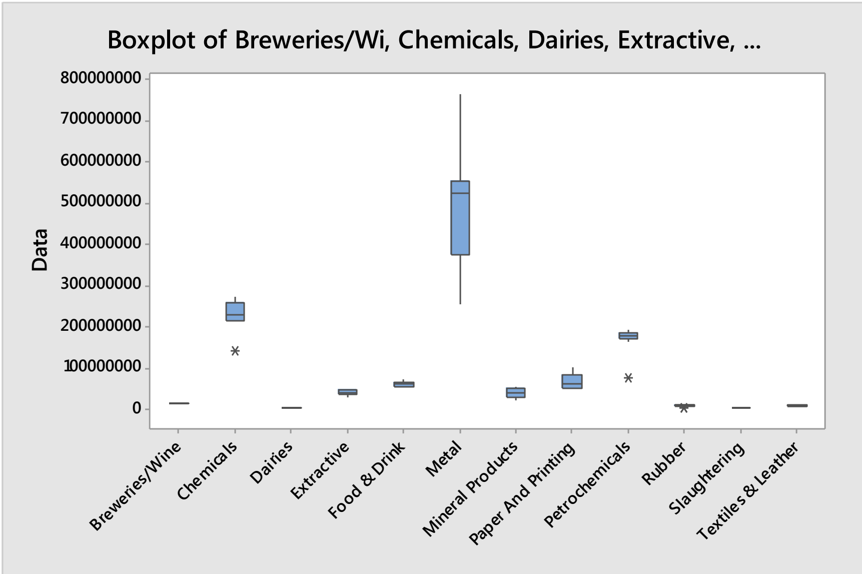

Figure 6.36: Boxplot of water use by main water intensive industrial products in England and Wales

The side-by-side boxplots of water use by the most water intensive industrial products in England and Wales above (figure 6.36), reveal two outliers, the first is seen in the boxplot of chemicals while the second is associated with the boxplot of petrochemicals. Even as both products constitute two of the five most intensive water using products, the outliers have been studied and it is confirmed that they do not constitute any spuriousness. Further observing the box and whiskers plot above, it is clearly seen that the mean, interquartile range, 25^{th}, 50^{th} and 75^{th} percentiles of *"Metal"* are significantly higher than those of others, with its distribution slightly skewed to the right. It is also observed that slaughtering has the lowest water use mean. To view these water use levels across a period of time, we will produce time series of the water use by these products.

6.18.2 Water intensive industrial products in England and Wales

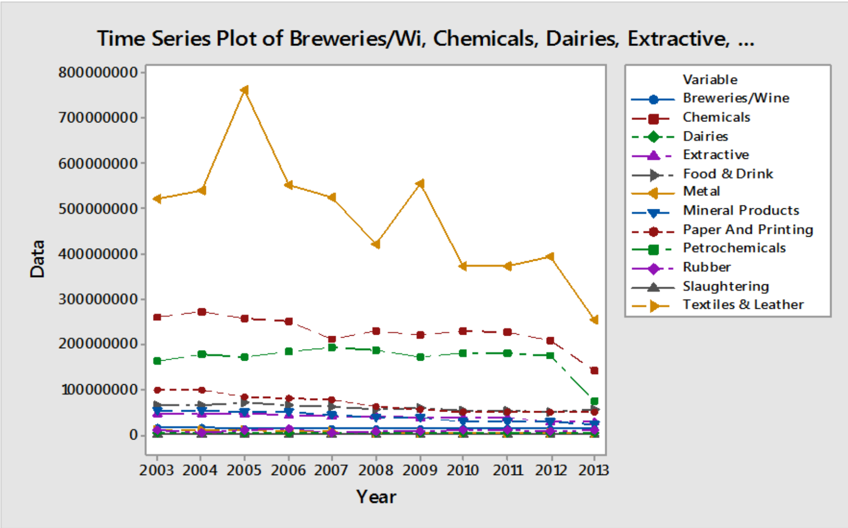

Figure 6.37: Time series plot of most water intensive industrial products in England and Wales

The time series plot of water use trend in England and Wales, over years, is revealed as figure 6.37. Although water use by the Metal is significantly the highest throughout the entire years under investigation, followed by that of Chemicals, then Petrochemicals, but the entire series clearly follow a downward trend. This depicts a general declining pattern of water use in the industrial sectors of England and Wales which actually has the highest number of industries and population. To this end, a trend analysis will be conducted on five of the most water intensive products to confirm the exact pattern (data plots, fits and forecast) associated with the products.

6.18.3 Trend analysis of water use for manufacture of metals in England and Wales

Hypothesis (H_0): There is a growing trend in water use for manufacture of metals in England and Wales, over time.

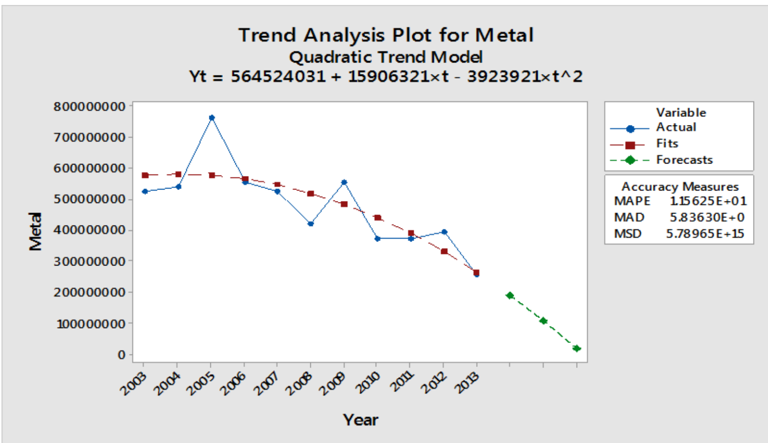

Figure 6.38: Trend analysis plot of water use for manufacture of Metals in England and Wales

Figure 6.38 provides the result of a trend analysis of water use for the manufacture of Metals in England and Wales. Critically observing the actual data plot, fits and forecasts, we can conclude that water use for manufacture of Metals shows a steeply declining trend with a seasonal pattern which is relatively consistent with the fitted and forecast model. As the result of the trend analysis generally reveals a declining trend in water use, we reject the null hypothesis that there is a growing trend in water use for the manufacture of metals and accept the alternative that there is a declining trend in water use for manufacture of Metals in England and Wales.

6.18.4 Trend analysis of water use for manufacture of chemicals in England and Wales

Hypothesis (H_0): There is a growing trend in water use for manufacture of Chemicals in England and Wales over time.

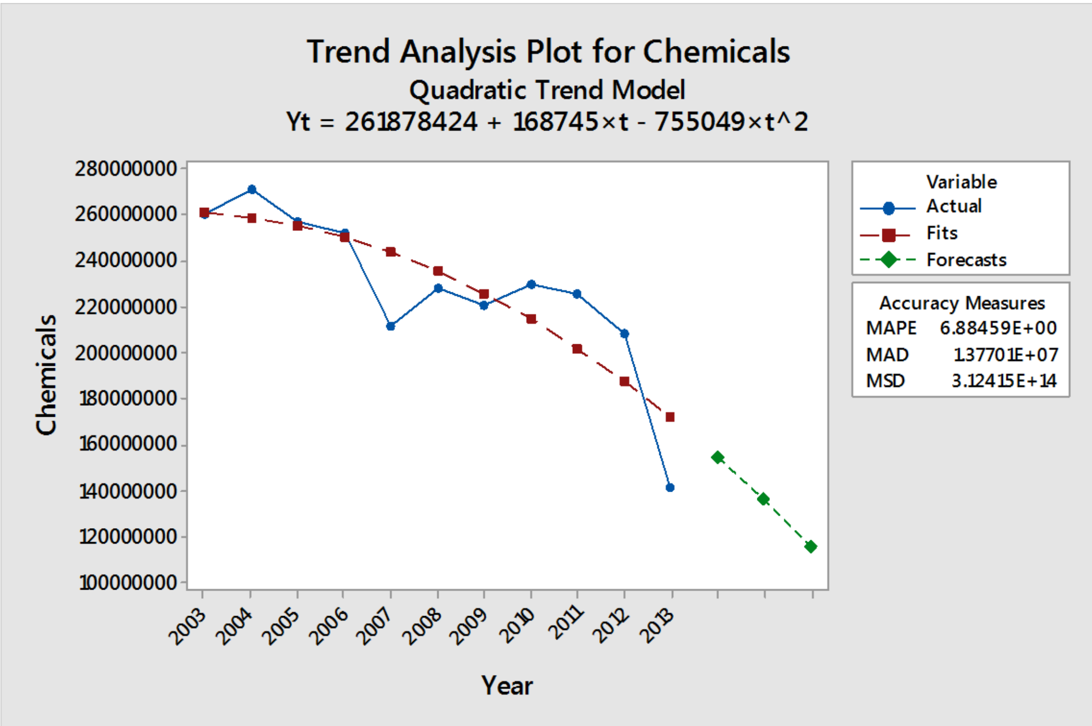

Figure 6.39: Trend analysis plot of water use for manufacture of chemicals in England and Wales

Observing the trend analysis plot for manufacture of Chemicals in England and Wales, over time (figure 6.39), it is seen that the actual data plot, fits and forecasts, all reveal a declining trend with a seasonal pattern which is closely consistent with the fitted and forecast model. As the result of the trend analysis generally shows a declining trend in water use, we reject the null hypothesis that there is a growing trend in water use for manufacture of chemicals and accept the alternative which upholds that the trend is rather declining.

6.18.5 Trend analysis of water use for manufacture of petrochemicals in England and Wales

Hypothesis (H_0): There is a growing trend in water use for manufacture of petrochemicals in England and Wales over time.

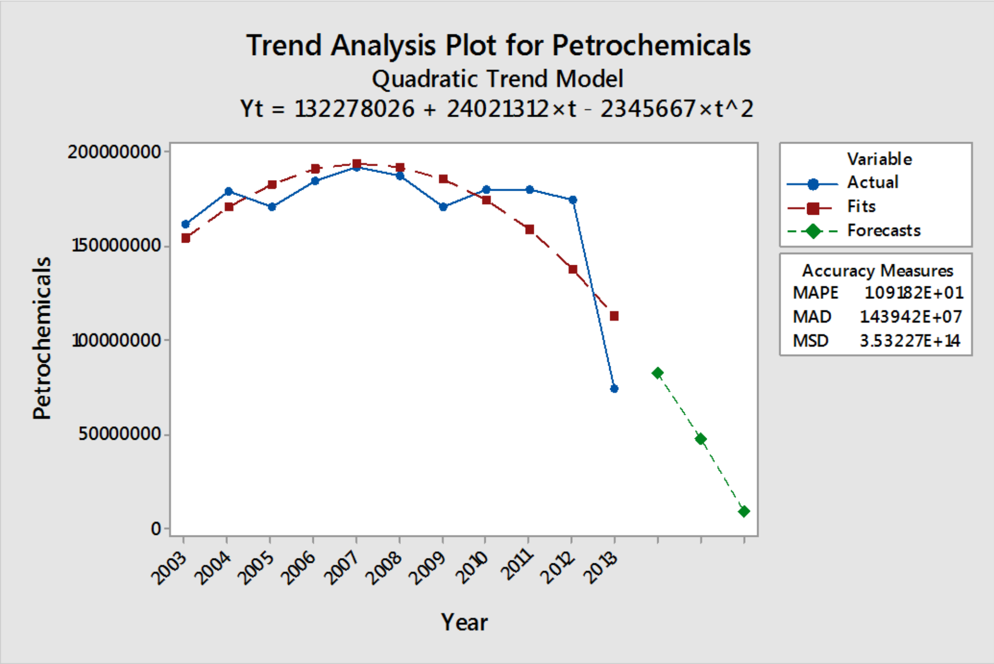

Figure 6.40: Trend analysis plot of water use for manufacture of petrochemicals in England and Wales

As clearly shown in the trend analysis plot for manufacture of petrochemicals in England and Wales over time (see figure 6.40), the actual data plot, fitted model (drawn using the quadratic trend equation: Y_t = 132278026 + 24021312×t - 2345667×t^^{2}) and the forecasts, all reveal a declining trend with a seasonal pattern which is almost parallel to the fitted and forecast model. As the result of the trend analysis follows a declining trend in water use, we reject the null hypothesis that there is a growing trend in water use for manufacture of petrochemicals and accept the alternative which upholds that the water use trend is steeply declining.

6.18.6 Trend analysis of water use for manufacturing paper and printing products in England and Wales

Hypothesis (H_0): There is a growing trend in water use for manufacturing paper and printing products in England and Wales over time.

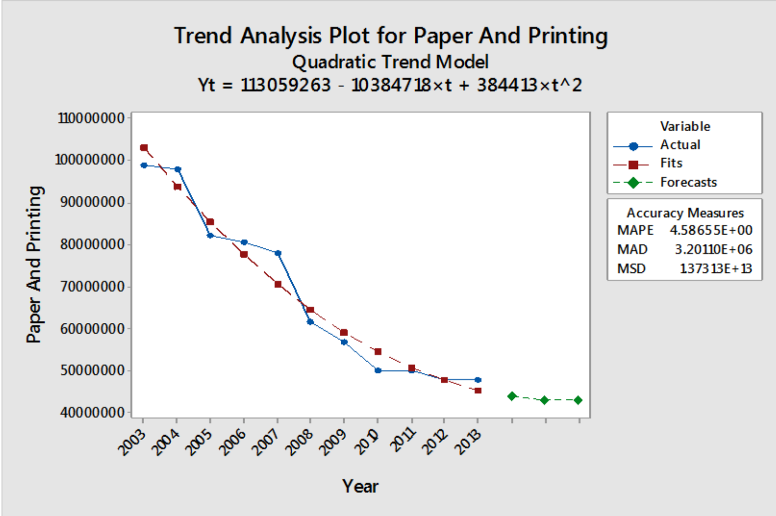

Figure 6.41: Trend analysis of water use for manufacturing paper and printing products in England and Wales

Observing the trend analysis plot for water use in manufacturing paper and printing products in England and Wales, over time (figure 6.41), it is deduced that the actual data plot, fits and forecasts, all show a declining trend with a seasonal pattern which is almost parallel to the fitted and forecast model. As the result of the trend analysis generally shows a declining trend in water use, we reject the null hypothesis that there is a growing trend in water use for manufacture of paper and printing products and accept the alternative which upholds that the trend is consistently declining.

6.18.7 Trend analysis of water use by food and drinks products in England & Wales

Hypothesis (H_0): There is a growing trend in water use by food and drink products in England and Wales over time.

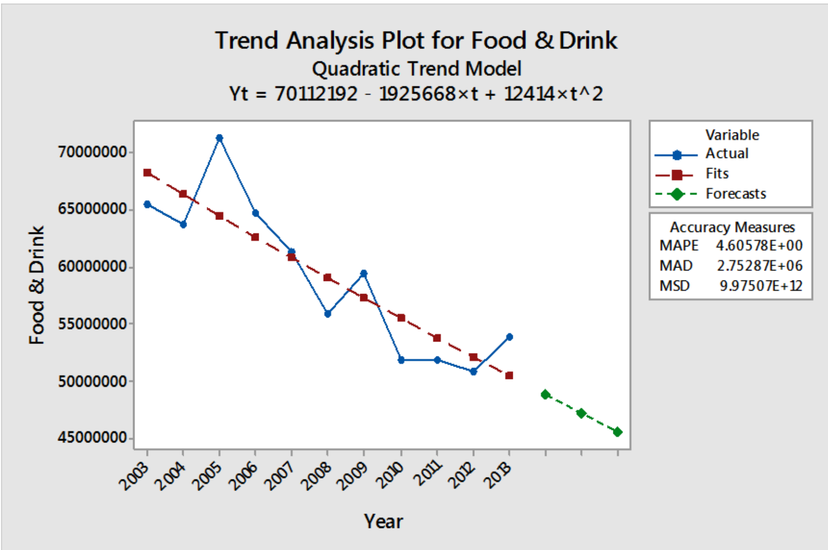

Figure 6.42: Trend analysis plot of water use by food and drinks products in England & Wales

Figure 6.42 is a trend analysis result for the water use by food and drinks products in England and Wales. Carefully observing the actual data plot, fits and forecasts, we can infer that water use by food and drinks products is sharply declining with a seasonal pattern which is relatively consistent with the fitted and forecast model. As the result of the trend analysis generally reveals a declining trend in water use, we reject the null hypothesis that there is a growing trend in water use by food and drinks products and accept the alternative that there is a declining trend in the water use by food and drinks products in England and Wales.

6.19 Water use by main water intensive industrial products in Northern Ireland

6.19.1 Data summary of water use by main water intensive industrial products in Northern Ireland

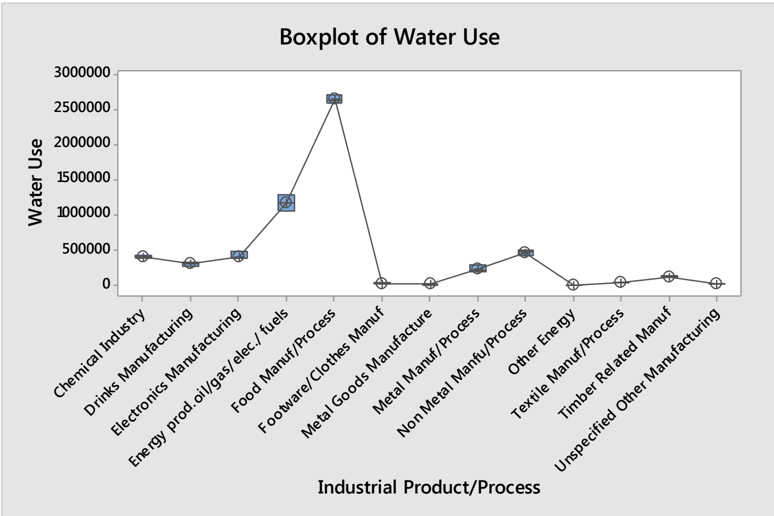

Figure 6.43: Boxplot of water use by main water intensive industrial products in Northern Ireland

The above side-by-side is a boxplot of water use by the considered most water intensive industrial products in Northern Ireland (figure 6.43). The figure reveals no outliers and shows symmetry of data distribution with none of the distributions being skewed to the right or left. From the boxplots, it is evident that the mean and median water use value, 25th, 50th and 75th percentiles of the food/manufacturing product/process are the highest; although the interquartile range of the energy production, oil/gas /electricity / fuels is higher than that of the food/manufacturing product/process. Accordingly, *“Metal Manufacture”* and *“Other energy”* have the lowest mean water values.

6.19.2 Major water intensive industrial products in Northern Ireland

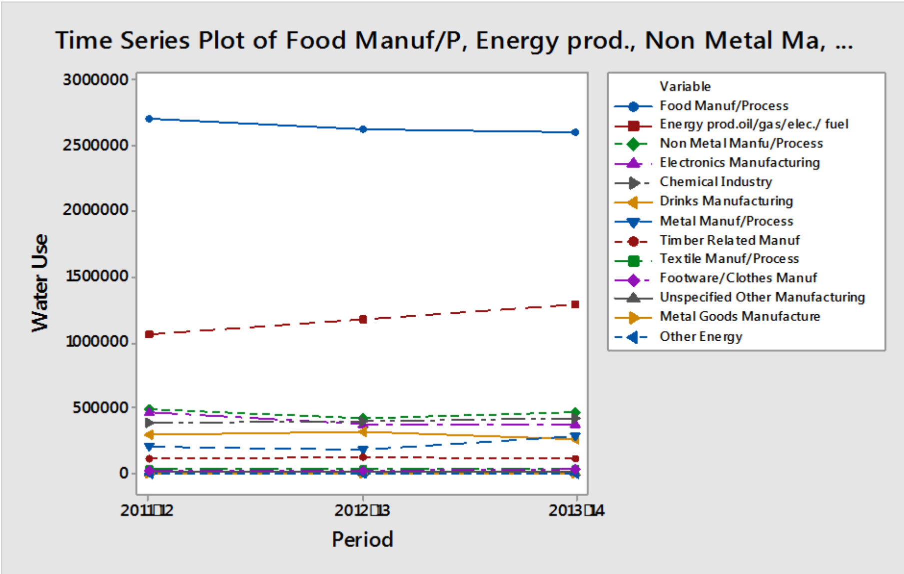

Figure 6.44: Time series plot of major water intensive industrial products

The above time series plot of water use trend in Northern Ireland, over years, shows that water use for manufacture of food is the highest in Northern Ireland, though the trend seems to be declining (figure 6.44). The next most water intensive process which is the production of Energy from oil/gas reveals a rather growing trend. Water use by the other products / processes shows a relatively flat or non-progressing trend.

6.19.3 Trend analysis of water use for manufacture of food

Hypothesis (H_0): There is a growing trend in water use for food manufacture in Northern Ireland over time

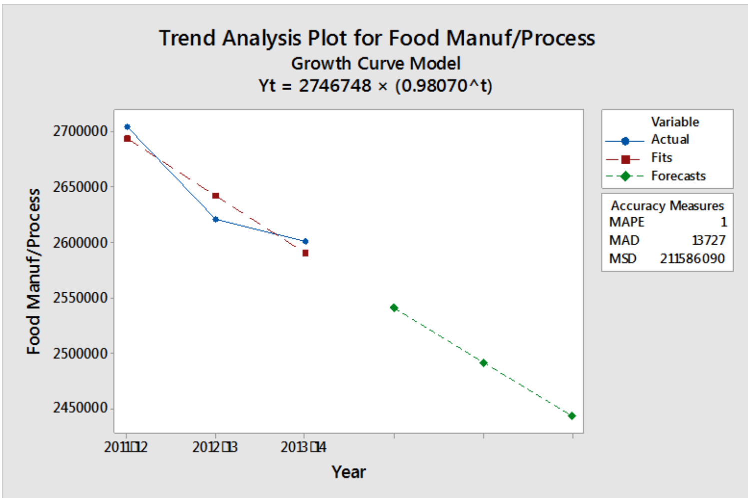

Figure 6.45: Trend analysis plot of water use for manufacture of food

As clearly revealed in figure 6.45 (above), the actual data plot, fits and forecasts, all show a declining trend with a seasonal pattern which is relatively consistent with the fitted and forecast model. As the result of the trend analysis shows a declining trend in water use, we reject the null hypothesis that there is a growing trend in water use for manufacture of food, and accept the alternative which upholds that the trend is rather declining.

6.19.4 Energy production and chemical industry water use trend analyses

Hypothesis (H_0): There is a growing trend in water use by the chemical industry and for energy production in Northern Ireland over time.

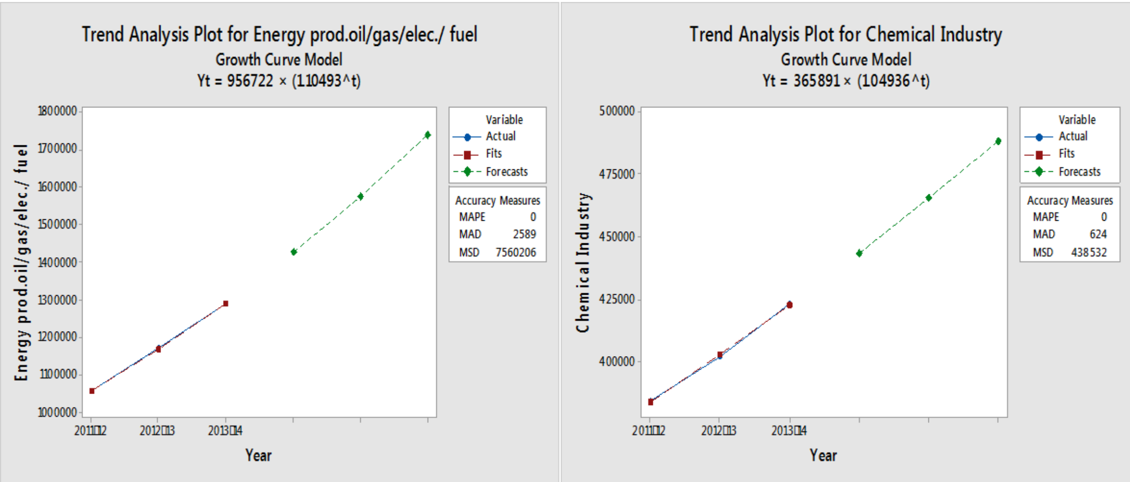

Figure 6.46: Trend analysis plot of water use for energy production and by the chemical industry

It is seen from the Minitab trend analysis of water use by the chemical industry and for energy production above (figure 6.46), that the growth curve equation was used to construct the fitted model. It is also evident from the actual data plot, fits and forecasts that water use for energy production and by the chemical industry shows a growing trend with a seasonal pattern which is comparatively consistent with the fitted and forecast model. As the chart generally shows a growing trend in water use, we accept the null hypothesis that there is a growing trend in water use for electricity generation in Northern Ireland, over time, and reject the alternative.

6.19.5 Trend analysis of water use for the manufacture of non-metals and electronics

Hypothesis (H_0): There is a growing trend in water use for the manufacture of non-metals and electronics in Northern Ireland over time.

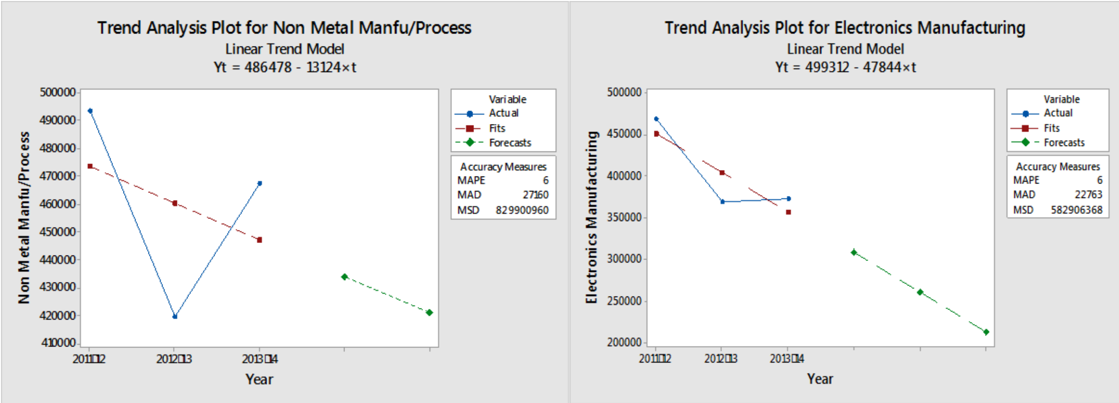

Figure 6.47: Trend analysis plot of water use for the manufacture of non-metals and electronics

The above figure provides results of trend analyses for the manufacture of non-metals and electronics in Northern Ireland (figure 6.47). Observing the actual data plot, fits and forecasts, we conclude that water use for both the manufacture of non-metals and electronics show a declining trend with a seasonal pattern which is not very consistent with the fitted and forecast model. As the result of the trend analysis generally depicts a declining trend in water use, we reject the null hypothesis that there is a growing trend in water use for the manufacture of non-metals and electronics and accept the alternative that there is a rather declining trend in the use of water for the manufacture of non-metals and electronics in Northern Ireland.

6.20 Energy consumption rates of major UK industrial processes *(Test of Hypothesis 6)*

i) The Null Hypothesis (H_0)

Energy consumption rates of major UK industrial processes have remained equal over years: $\mu_1 = \mu_2 = \mu_3 = \mu_4$

ii) The Alternative Hypothesis (H_A)

At least two of the population means differ from each other.

iii) Decision rule for statistical analysis

Using the P-Value method and choosing a significance level of 0.05, reject the null hypothesis if the P-Value is less than the adopted significance level.

6.20.1 Normality of data residuals (errors)

From the test of normality result (see Appendix A, subsection 8.12.1), it was established that the original data was not normal (P-value = <0.005). Thus using Johnson's method, the data was transformed and the probability plot for the transformed data gave a P-Value of 0.260 which is higher than the alpha (α) value of 0.05. We then conclude that the current data to be use for the analysis is normally distributed.

6.21 Interpretation of correlation of variables output

Looking at the Minitab output for the hypothesis test for correlation (Appendix A, subsection 8.12.2), a common trend is observed in the relationships between the Year and each of the industrial sectors; that is, there is a strong negative relationship between the years and rates of energy consumption for each industrial process. The least of the negative relationships is revealed in the Pearson's correlation value of -0.890 which is the relationship that exists between the Year and the Iron and Steel production process. Accordingly, it is clearly observed that for all pairs of variables, the test static or calculated P-Value is 0.000; whereas, the least value of the Pearson correlation for the four major industrial sectors (excluding the one related to the years) is 0.916. Thus, we conclude that there is a strong relationship between the variables used for this analysis. We then continue with the regression analysis.

6.22 Interpretation of regression analysis output

Results of the regression analysis gotten from Minitab are revealed in Appendix A, subsection 8.12.3. From the analysis, the calculated R^2 of 93.99% means that 93.99% of the variation in the energy consumption is explained by the regression module or the four major industrial sectors. Also, as observed in the ANOVA output, the P-Value of each variable is 0.000 which is lower than the alpha (α) value of 0.05. Thus, there is a statistically significant difference between the *"energy use per unit of product"* and the *"Year"*; and the *"energy use per unit of product"* and the *"Industrial sectors"*. Accordingly, it is noticed that each industrial product has a separate regression model; to this, Minitab conducts an individual t-test with the null hypotheses H_0: $\beta_1 = 0$; H_0: $\beta_2 = 0$ and the alternative hypotheses being H_0: $\beta_1 \neq 0$; H_0: $\beta_2 \neq 0$. Results of these t-tests still show that the highest P-Value gotten from the investigation is 0.028 (Food, drink & tobacco), which is also lower than the alpha (α) value of 0.05.

Based on these results, we now have enough statistical evidence to reject the null hypothesis and accept the alternative which is that energy consumption rates of major UK industrial sectors is not equal over years. However, to further understand the relationship between the four major industrial processes, we will investigate the factors of this design, produce an interaction plot and examine same for potential interaction(s).

6.23 Factorial design and interaction plot

As defined by Bryman and Cramer (1996, p.191), *"an interaction is when the effect of one variable is not the same under all the conditions of the other variables"*; thus, *"an interaction occurs when two lines representing the third variable are not parallel"*. These variables are known as factors and the number of groups that make up a factor is known as *"levels of the factor"*. For this analysis, the four major industrial sectors that are investigated create a four-level factor; whereas, *"Energy consumption rates"* and the *"Years"* constitute a two – level factor. Hence, we say that this is a 4 x 2 *factorial* design. Suffice it that studies aimed at investigating effects of two or more factors are known as *factorial* designs (Bryman and Cramer 1996, p.191).

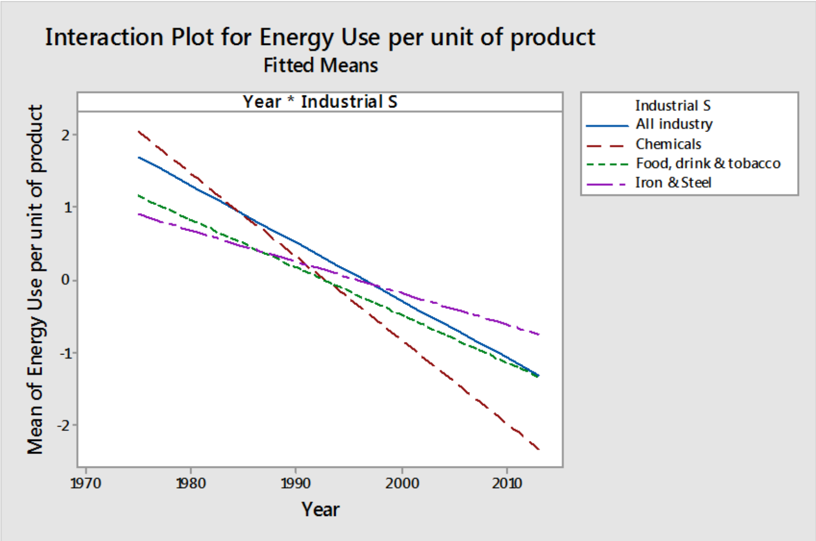

Figure 6.48: Interaction plot for energy use per unit of product

From the interaction plot above (figure 6.48), it is evident that the energy use per unit product changes significantly from one year to the other. A general interpretation of the plot is that change in energy consumption rates from one year to the other depends on specific industrial processes. This is so because from 1970 to 2012, energy consumption rates for the four industrial sectors have continuously been on the decline; yet, the decrease in energy use is more in the Chemicals production sector than it is in the Iron and steel. So given that the plot lines of the industrial sectors are not parallel and each intersects the remaining three, we conclude that there are significant energy use per unit product interactions among the assessed industrial sectors, due to the strong effect of change in time (over years).

Chapter Seven

7.0 Introduction

In this chapter, a clear-cut summary of diverse research efforts and deductions is presented. It is intended that this chapter shall neatly explain the findings made as a result of the review of several cognate literature and detailed empirical analyses carried out. Whereas, the ultimate aim of academic researches is to solve identified problems, this section proffers cost-effective technical measures of water conservation in the UK industrial arena. However, in areas where this study is unable to successfully cover its entire proposed targets sequel to prevailing circumstances, the attendant research limitations will be outlined. This will herald the need to or not to open the work to further researches.

7.1 Summary of major findings

7.1.1 Findings from literature review

Historically, management of water use by UK industry has been surmised to be complex and difficult, following the heaving industrial subsectors; this has raised a growing concern over the sustainability of water-related industrial practices and processes. Further, given the complex nature of the industrial sector and the difficulty associated with collecting data on water use by the industrial subsectors, very few researches on water use by industry have been published. Although, pursuant to the very high water use by UK industry relative to the domestic and agricultural sectors, some trade bodies such as WRAP and Dairy UK, etc., have started writing guides / manuals or annual reports on how to minimise water use in some of the vast industrial divisions.

Accordingly, UK has been identified as a country with *"low"* water availability relative to its general designation as a *"wet country"* and fresh water in regions such as the East and South Anglia (England), is already over-exploited, yet population and industrial activities in these areas remain the highest while their annual rainfall is always the lowest.

Benchmarking, a quality management tool has been theoretically identified as a veritable tool for driving behavioural changes and enhancing the sustainability credential of the UK industrial sector (with its teeming subsectors), in terms of its fresh water use.

Also, from the literature review, a complimentary operation of water and energy has been established as a great way of conserving these indispensable resources. It is noted that in the past, water and energy have been treated autonomously by numerous authors either due to the complex challenges associated with assessing both in concert or given their discrete economic roles. However, contemporary issues of phenomenal climate variability, sustainability, industrialization, population growth and security of supply, present a dire need for an integrated approach to policy formulation and design of water-energy systems in the UK. It is believed that this assessment of water and energy resources in tandem will help improve the design and operation strategies of water and energy systems; create more secure integrated services in UK and most importantly, enhance the net economic status of UK industrial organisations.

7.1.2 Findings from data analysis

Data analyses of this study focused on six major hypotheses and over 40 sub-hypothesis; key findings of these assessments are summarized under these six broad concerns.

The first hypothesis bordered on the statistical relationship between UK's population growth and its use of water for industrial purposes. Based on the analyses results, it was discovered that, for the period covered, in England, water use by the manufacturing sector – for electricity generation and for the industry as a whole, kept declining relative to the steady increase in the region's population growth. This trend is exactly applicable to Scotland; however in Wales, water use for electricity supply has rather kept increasing with the increasing population of the region. Further, in Wales, water use by the manufacturing sector and the industry (combination of the manufacturing and the electricity supply) continued decreasing against Wales' growing population. For Northern Ireland; it was revealed that for manufacturing, electricity generation and the industrial sector, water use kept increasing alongside the region's population growth.

The second hypothesis touched on the variation in annual water use among the industrial, agricultural and domestic sectors of the UK. Still segregating the assessment, it was statistically concluded that for all three UK regions, water use by the industrial sector remained the highest and differences between these sectors are statistically significant.

To corroborate if there are a significant variations in annual water use (relative to production) by UK production (manufacturing) companies, data from several firms were collected and tested. This formed the third hypothesis. Results showed that statistically, there is a significant variation in water use among a substantial number of the companies investigated.

The fourth hypothesis is about *"Absolute"* freshwater water use by the industrial subsectors or divisions (classified according to the SIC). Suffice it that the term *"absolute"* means that the data is not normalised, that is, not measured per unit of product or production. Results gotten from this test showed that out of the great number of industrial subsectors that were assessed, just a few pairs showed statistical significant differences. This outcome is highly suggestive; it clearly proves that the best form of data for comparison of performance or deduction of statistically significant variation(s) remains in a normalised form.

With the aim of establishing if there is a steady increase or decline in water use by individual industrial sectors, hypothesis 5 was proposed. The hypothesis was set to verify if there is a growing trend in water use by major water intensive products of the UK industrial sector, over time. For each region of the four UK regions, five most water intensive products were further investigated as individual plots with forecasts. For England and Wales, the highest users of water for industrial purposes (ranked from the highest) include: Manufacture of metals; Manufacture of chemicals; Manufacture of petrochemicals; Manufacturing paper and printing products; and Food and drinks products. However, due to the application of more stringent water and carbon regimes, and higher cost of production materials in UK, there is currently a growing trend in the emigration of manufacturing and food industries from the UK. This explains the sharp and steady decline in water use among the five industrial divisions of England and Wales. Accordingly, for Scotland, the five most water intensive products include: Manufacture of distilled potable water; Manufacture of basic pharmaceutical; Electricity generation; Electricity transmission, distribution and supply; and Manufacture of beer. Of these, water for Water use for manufacture of distilled potable water and Water use for electricity generation showed an upward trend of water use; while the remaining showed a downward trend. Lastly, water use for industrial purposes in Northern Ireland seems to follow a similar trend as that of Scotland.

The last hypothesis for this study was aimed at investigating UK industrial products with the highest energy consumption per unit of production. The outcome of this research revealed that the most energy intensive products are also the highest Water Using Products (WUPs). A clear understanding of this inextricable water-energy nexus is very important because, as establish in the literature review section, water use in the industrial arena is highly dependent on energy for its abstraction, treatment, distribution and discharge in the used form (wastewater); whereas, energy requires water for its generation and manufacture, and plant cooling.

7.1.3 Meeting the aim and objectives of this study

Central to this study is the benchmarking or performance comparison of industrial water use in the UK, the goal being to identify water use best practices associated with the sector's processes. To achieve this, milestone objectives were outlined; the extent to which these objectives are achieved are thus gauged:

a) Objective 1

The first objective is focused on critically reviewing cognate literature on benchmarking of industrial use of water globally, and specifically in the United Kingdom. From the extant literature of this study, it is evident that the industrial sector has suffered so many years of inattention by academics and industrial stakeholders, mainly due to its myriads of products and lack/insufficiency of requisite data that would enable a comprehensive benchmarking of the sector's water use. However, with the emerging sustainability strategies such as the Federation House Commitment towards achieving a 20% cut in water use in the food and drink sector by 2020, several organisations in the industrial sector have now realized the indispensable need to reduce their water use rates. As exactly reported by the Waste and Resources Action Programme (WRAP) (2014, p.1), *"Between 2007 and 2013, signatories collectively made a 15.6% reduction in their water use (excluding that in product)"; … "this reduction is equivalent to 6.1 million m^3 water or 2,430 Olympic-size swimming pools, and is three-quarters of the way towards hitting 20% reduction by 2020".*

In a nutshell, the literature review of this study confirms that majority of UK industrial sectors have now seen the need for benchmarking their performance in order to minimise waste and water-related costs, and boost their productivity and overall competiveness in business.

b) Objective 2

The second objective of this research is to identify prevailing gaps in the use of water by the UK industrial sector. These gaps/windows have been clearly highlighted in this study. Some of the key research windows include that over the years, industrial water use in the UK has remained the highest (circa 70 – 80% each year) relative to those of other European countries. Also, even as there exist several peer reviewed literature, water use standards and benchmarks for domestic and agricultural processes (some of which are published annually), none cover the industrial sector with its over 1000 divisions. Further, there are numerous tools developed by organisations for sustainability in the domestic arena, but few are for industrial processes; more even, these available few mainly focus on water scarcity and stress rather than on how to converse water use per unit of industrial product/production. Other teeming gaps can be accessed in the *"Introduction"* and *"Statement of the problems"* sections of this thesis.

c) Objective 3

The third objective concentrated on sourcing and collating requisite data on industrial use of water in UK, broken down in accordance with the UK Standard Industrial Classification (SIC) of economic activities. This was successfully achieved, and the data was subsequently used in conducting the comprehensive data analyses of this study as revealed in the *"Analysis of Data and Interpretation of Results"* section (chapter six).

d) Objective 4

The fourth objective is concerned with deducing and adopting Key Performance Indicators (KPIs) and metrics for conducting the benchmarking of water use in the UK industrial sector. From the literature review, several KPIs and metrics where discovered, but few applied to this research, these are summarised in table 7.1.

KPI	Metric (Unit)
Total water (absolute)	m^3
Total water (relative to production)	m^3/tonne of product
Consumptive water	m^3
Process water (absolute)	m^3
Process water (relative to production)	m^3/tonne of product
Cleaning water	m^3
Cooling water	m^3
Water re-use	% (by volume)

Table 7.1: KPIs and Metris (Units) used in developing the *i*-Water Benchmarking Tool

Adapted from: WRAP (2013a, p.11)

These KPIs and metrics were fundamentally used to develop the specific KPIs and metrics that are currently incorporated into the *i*-Water Benchmarking Tool. Leaving out the KPIs because of the space it will take if added to this section, the corresponding metrics contained in the *i*-Water Benchmarking Tool are: Litre(s)/bird; Litre(s)/kg of bird; Litre(s)/t turkey carcass; % of water consumption for entire production; Litre(s)/kg slaughtered animal; Litre(s)/kg; m^3/t of finished product; m^3/tonne carcass; Litre(s)/animal; Litre(s)/stomach; Litre(s)/tray; Litre(s)/t pig carcass; Litre(s)/pig; Litre(s)/h; Litre(s)/pig intestine; % of water consumption; Litre(s)/t of carcass; m^3/tonne of product; m^3/t; Litre(s)/head; m^3/tonne; %; m^3/tonne of raw material; Litre(s)/t poultry carcass; Litre(s)/carcass; Litre(s)/t sheep carcass; Litre(s)/tonne; Litre(s)/t cattle carcass; Litre(s)/t raw material; kg/t raw material; Litre(s)/t by-product rendered; Litre(s)/t blood; m^3/yr; Litre(s)/t feather and hair rendered; kg/t MBM; m^3/tonne ; Litre(s)/t fish treated; m^3/t of product; Litre(s)/t; m^3/t oil; m^3/t oil seed; m^3/t of oil; m^3/t of olive oil produced; Litre(s)/t soap; m^3/t unrefined oil; kg/t unrefined oil; Litre(s)/litres of product; L/Kg intake; Litre/kg product; kg/tonne; m^3/litre; Litre(s)/litre of received milk; Litre(s)/litre of milk; Litre(s)/litre of processed milk; Litre(s)/litre processed milk; Litre(s)/litre raw material; Litre(s)/kg; processed milk; Litre(s)/flush; Litre(s)/litre; Litre(s)/t cheese; m^3/t raw milk; Litre(s)/kg of produced ice-cream; m^3/kg; Litre(s)/kg ice cream; m^3/t of pasta; hl/hl; Litre(s)/hl; Litre(s)/bottle; hl/hl beer; m^3/m^3 of product; m^3/hl of beer produced; hl water/hl beer sold; hl/hl beer sold; m^3/t DDGS produced; Litre(s)/t raw coffee; m^3/m^3; m^3/tonne cane; m^3/t sugar produced; m^3/hl; Litre(s)/litre of Beer; Litre(s)/litre of finished beverage; Litre(s)/KWh of Electricity generated; m^3/t board; m^3/t of paper; and Litre(s)/kg product.

e) Objective 5

Objective five is to develop and standardize a benchmarking tool which integrates the adopted KPIs and metrics using a suitable software development platform. This is now completed with the pre-alpha, alpha and beta tests successfully completed. The Tool was first tested by Ondeo Industrial water and SUEZ, then by UK BCSD (the research funder). The feedbacks received were used to further develop and improve the capability of the Tool. One of such feedbacks was the inclusion of an economic indices to enable users understand the implications of excessive water use in economic terms. Lastly, two VBA experts tested the Tool, and after the final debugging, the Tool was considered as a *"Release candidate"*.

f) Objective 6

The sixth objective is to empirically analyse how much water is used by each industrial subsector, benchmark the comparable processes and identify corresponding water-intensive activities. These have now been fully accomplished. Chapter six *"Analysis of Data and Interpretation of Results"* covers the analysis of water use in the industrial subsectors and interpretation of the Minitab (statistical analysis software) outputs. A condensed summary of these analyses are encapsulated in section 7.1.2 of this chapter, while the benchmarking exercise is revealed in chapter five with results of the assessment located in section 5.3.2, titled: *"Results of the performance benchmarking exercise"*.

g) Objective 7

Objective seven being *"To make suitable recommendations on best practice industrial water saving measures based on the study findings"*, clearly helps to achieve a key part of the principal aim of this study; the part is: *"identification of best practices associated with industrial water in the UK"*. This objective has been mainly covered in chapter two where the industrial sectors of interest are detailed, with how to optimally use water in their processes clearly highlighted. In addition, general industrial water use best practices are explicitly delineated in the *"Deduced best practice resource saving measures for industrial processes"* section of this study (2.9).

7.1.4 Confirming that the research questions are answered

i) Research Question 1

The first question of this study is: Why should industrial water use in the UK be benchmarked? Put straight, this question borders on the rationale behind this research; and this has been detailed in both the introductory and statement of problems sections. However, key to the points raised in the above-mentioned sections is that over years, industrial water use in the UK has been the highest (70 – 80% share) relative to those of other European countries. Suffice it that large water use by the industrial sector could in turn mean that there are great potentials for water savings in the sector. Also, there are very few academic studies on water use in the industrial arena; majority relate to the domestic and agricultural sectors. Further, UK is classified as having low water availability per capita per year; thus, a sustainable use of the UK's fresh water remains indispensable. It is therefore considered that benchmarking industrial water use will help reveal water intensive industrial products and processes.

ii) Research Question 2

Constituting the research question 2, the study sought to deduce the most water-intensive processes and practices in the industrial sector. Results of the analysis conducted using the collected data show that for England and Wales, the five highest users of water for industrial purposes (ranked from the highest to lowest) include: Manufacture of metals; Manufacture of chemicals; Manufacture of petrochemicals; Manufacture of paper and printing products; and production of Food and drinks. Also, for Scotland, the five most water intensive processes include: Manufacture of distilled potable water; Manufacture of basic pharmaceutical; Electricity generation; Electricity transmission, distribution and supply; and Manufacture of beer. Lastly, in Northern Ireland the five highest to lowest water users are: Manufacture of food; Energy production; manufacture of chemicals; manufacture of non-metals and manufacture of electronics.

iii) Research Question 3

The third question is: UK is a highly industrialised country; thus, its industrial water use will remain high and even increase with the imminent population increase over the coming years. How true is this statement? This question is comprehensively answered in Section 7.1.2: *"Findings from data analysis"* under the summary of results gotten from testing the hypothesis which holds that: There is no statistical relationship between UK's population growth and its use of water for industrial purposes. This detail will not be repeated here to avoid duplications of findings.

iv) Research Question 4

Research question 4 is: What are the most appropriate water use metrics for benchmarking water use by industry in order to reveal the true performance status of the benchmarked Sites? To answer this question, there is need to refer to section 7.1.3 (that is, within chapter 7): *"Meeting the aim and objectives of this study"*. In the section 7.1.3, objective four focuses on deducing and adopting Key Performance Indicators (KPIs) and metrics for benchmarking of water use in the UK industrial sector. In this section, details of benchmarking metrics are provided. From these, it is inferred that the most appropriate water use metrics are metrics containing water use per unit of product or production not the water use (absolute). The water use (absolute) reflects water use per period but does not reveal if there is increase in production which should ideally increase the water use. In a nutshell the best water use data for benchmarking is the normalised data, that is, data with per unit product or production metric.

v) Research Question 5

Question five is: What are the possible water conservation strategies to optimally reduce water use by the UK industrial sub-sectors? This question is clearly consistent with objective 7 which is to make suitable recommendations on best practice industrial water saving measures based on the study findings. Answers to this question are therefore provided in section 7.1.3: *"Meeting the aim and objectives of this study"* under objective 7.

vi) Research Question 6

Is there any measurable relationship between UK water and energy use, constitute the research question six. From the study, the answer to this question is in the affirmative. Findings of the water-energy nexus appraisal reveal that energy use in the water sector has intensified by about 10% over the last eight years, with a 4% escalation to 9.012 TWh between 2009 and 2010 (Water UK, 2010). With the increasing stringent quality standards for water and wastewater processes, energy use in the water sector is predicted to keep increasing.

Also, the energy sector's water demand has continued to increase with the nation's growing energy needs, and accounts for approximately 32% of total freshwater abstraction in UK (Watson and Rai, 2013). In England and Wales alone, between 2000 and 2012, 76.03% of the total water abstraction was used for electricity supply, 15.51% for public water supply, 5.20% by industry (other), 3.15% for fish farming, while *"other water uses"* constituted 0.11%.

7.2 Conclusion

In the UK, water use benchmarks are nationally published to cover schools, offices and hospital buildings; however, due to the complex nature of the industrial sector and diversity of its processes, there is currently no existing set of water benchmarks for industrial buildings. However, various industrial processes have been individually mapped and best practice thresholds or benchmarks are gradually being developed to help moderate the measure of water used for different industrial processes. UK Envirowise has long been at the forefront of periodically publishing open access water benchmarks for various industrial processes under the SIC for economic activities. Whereas, the last published work from Envirowise was in 2007, stakeholders have variously sought more recent benchmarks. To this end, this research has sourced current benchmarks for industrial water processes. With these benchmarks, a robust software called *i*-Water Benchmarking Tool has been developed with the aim of making the Tool free for public use, so that industrial companies can benchmark their performance and identify key areas that require technical assessments and optimal water use.

From the statistical analyses, it is established that industrial water use in the UK is now significantly declining. This is considered as a welcome development given that with the steady increase in UK population coupled with its ever-growing industrialization, a complementary surge in water use by the industry was expected. Results also reveal that in contemporary times, most UK industrial firms are realising the economic gains of salvaging any excessive use of water on their sites.

It is pertinent to state that water conservation in the industrial arena is process – specific. This implies that optimal water savings require a good understanding of the water intensive processes. For instance, metals and chemicals manufacture will need more water for *"cooling"* relative to food and beverage or Paper and pulp which need more water for their *"processes"*.

By extension it was deduced from this study that both the water and energy sectors heavily rely on each other, as the output of one is the input of the other. It is believed that this assessment of water and energy resources in tandem will help improve the design and operation strategies of water-energy systems, enhance the sustainability credential of the associated undertakings and create more secure integrated services in the UK.

7.3 Recommendation for further research

Whereas, the complete structure of UK Standard Industrial Classification (2007) comprises of *"21 sections, 88 divisions, 272 groups, 615 classes and 191 subclasses"* (ONS 2007, p.2) this study covered five Divisions out of the existing 88. The Five divisions studied in this research include Manufacture of chemicals and chemical products (SIC division 20); Manufacture of basic metals (SIC division 24); Manufacture of paper and paper products (SIC division 17); Manufacture of beverages (SIC division 11), and Manufacture of food products (SIC division 10). It is therefore recommended that the remaining 83 divisions be benchmarked in order to determine how these sectors are performing in terms of their rates of water use, relative to the standard thresholds - benchmarks.

Appendices

8.0 Appendix A

8.1 Analyses outputs for England's industrial water use relative to its population growth over time *(Test of Hypothesis 1a)*

8.1.1 Probability plot of Standardized Residuals (England)

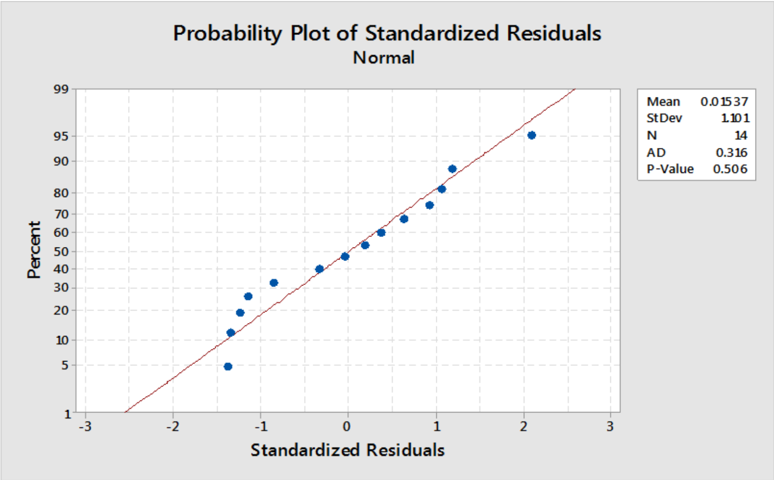

Figure 8.1: Probability plot of Standardized Residuals (England)

8.1.2 Correlation: Year, Water Use (Manufacturing Ind.), Population (England)

```
                         Year  Water Use (Manuf
Water Use (Manuf       -0.034
                        0.908

Population (Engl        0.995            -0.101
                        0.000             0.730

Cell Contents: Pearson correlation
               P-Value
```

8.2 Analyses outputs for Scotland's industrial water use relative to its population growth over time *(Test of Hypothesis 1b)*

8.2.1 Probability plot of Standardized Residuals (Scotland)

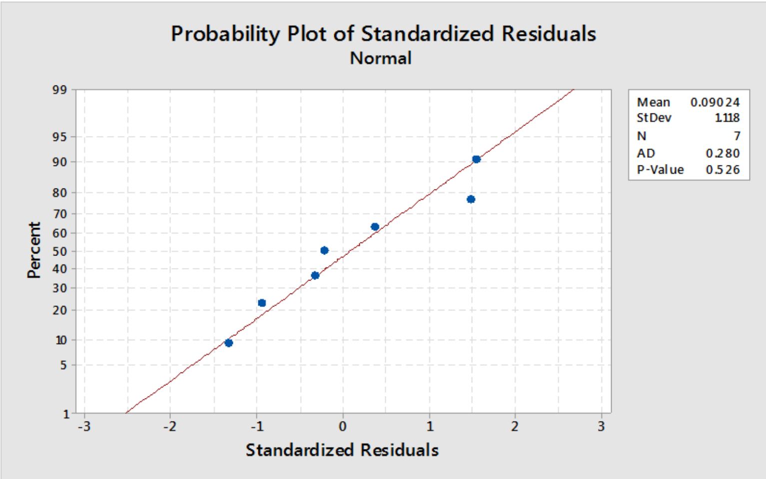

Figure 8.2: Probability plot of Standardized Residuals (Scotland)

8.2.2 Correlation: Year, Water Use (Manufacturing Ind.), Population (Scotland)

```
                              Year  Water Use (Manuf
Water Use (Manuf            -0.888
                             0.008

Population (Scot             0.994            -0.874
                             0.000             0.010

Cell Contents: Pearson correlation
               P-Value
```

8.2.3 Regression Analysis: Water Use (Manufacturing Ind.) versus Population (Scotland)

```
Analysis of Variance

Source                    DF       Adj SS       Adj MS  F-Value  P-Value
Regression                 1  1.64825E+13  1.64825E+13    16.25    0.010
  Population (Scotland)    1  1.64825E+13  1.64825E+13    16.25    0.010
Error                      5  5.07055E+12  1.01411E+12
Total                      6  2.15530E+13

Model Summary

      S    R-sq  R-sq(adj)  R-sq(pred)
1007030  76.47%     71.77%      45.68%

Coefficients

Term                        Coef   SE Coef  T-Value  P-Value   VIF
Constant               172119845  34614398     4.97    0.004
Population (Scotland)     -27.13      6.73    -4.03    0.010  1.00

Regression Equation

Water Use (Manufacturing Ind.) = 172119845 - 27.13 Population (Scotland)
```

8.3 Analyses outputs for Wales' industrial water use relative to its population growth over time *(Test of Hypothesis 1c)*

8.3.1 Probability plot of Standardized Residuals (Wales)

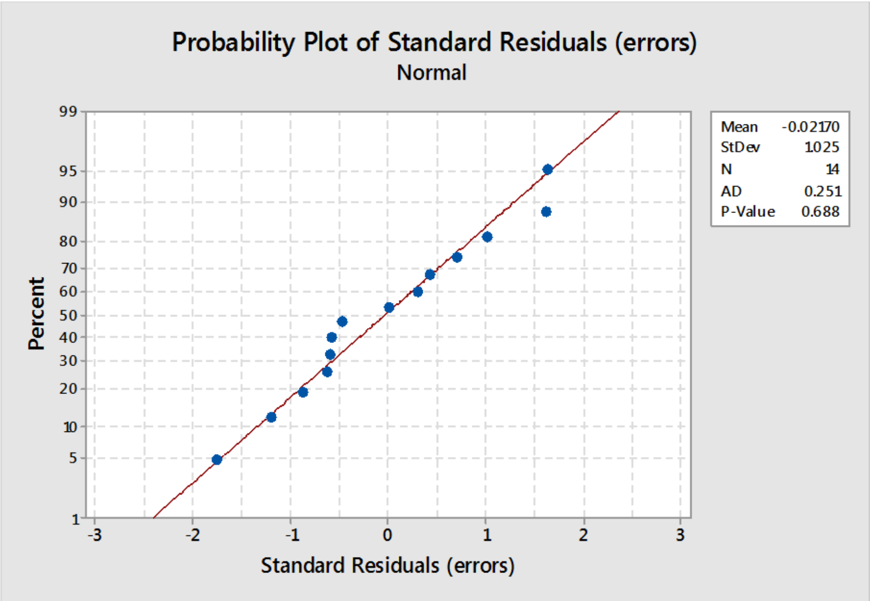

Figure 8.3: Probability plot of Standardized Residuals (Wales)

8.3.2 *Correlation: Water Use (Manufacturing Ind.), Population (Wales), Year*

	Water Use (Manuf	Population (Wale
Population (Wale	-0.828	
	0.000	
Year	-0.849	0.996
	0.000	0.000

Cell Contents: Pearson correlation
P-Value

8.3.3 *Regression Analysis: Water Use (Manufacturing Ind.) versus Population (Wales), Year*

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	2	43125	21563	17.41	0.000
Population (Wales)	1	2262	2262	1.83	0.204
Year	1	4244	4244	3.43	0.091
Error	11	13625	1239		
Total	13	56750			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
35.1937	75.99%	71.63%	61.05%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	91541	47944	1.91	0.083	
Population (Wales)	0.00241	0.00179	1.35	0.204	129.47
Year	-49.1	26.5	-1.85	0.091	129.47

Regression Equation

Water Use (Manufacturing Ind.) = 91541 + 0.00241 Population (Wales) - 49.1 Year

8.4 Analyses outputs for Northern Ireland's industrial water use relative to its population growth over time *(Test of Hypothesis 1d)*

8.4.1 *Probability plot of Standardized Residuals (Northern Ireland)*

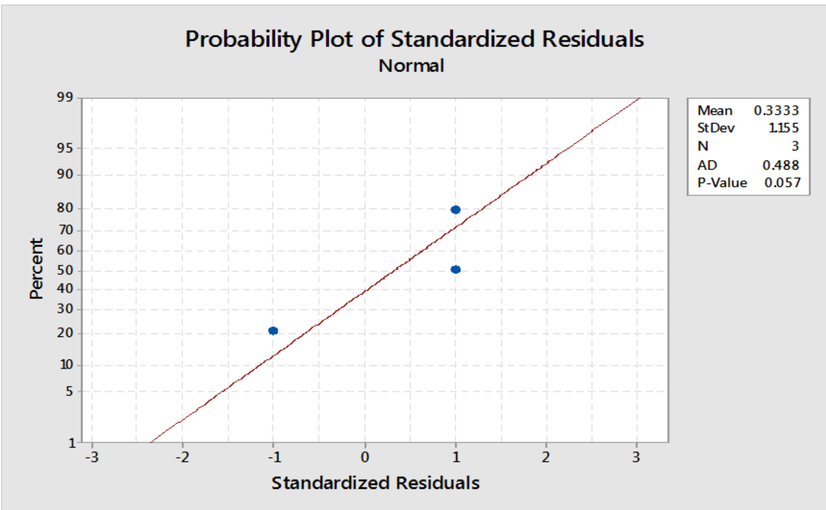

Figure 8.4: Probability plot of Standardized Residuals (Northern Ireland)

8.4.2 Correlation: Year, Water Use (Manufacturing Ind.), Population (Northern Ireland)

```
                          Year  Water Use (Manuf
Water Use (Manuf        -0.559
                         0.622

Population (Nort         0.993            -0.654
                         0.077             0.546

Cell Contents: Pearson correlation
               P-Value
```

8.5 Analyses outputs for industrial, domestic and agricultural shares of annual water use in England *(Test of Hypothesis 2a)*

8.5.1 Probability plot of data residuals (England)

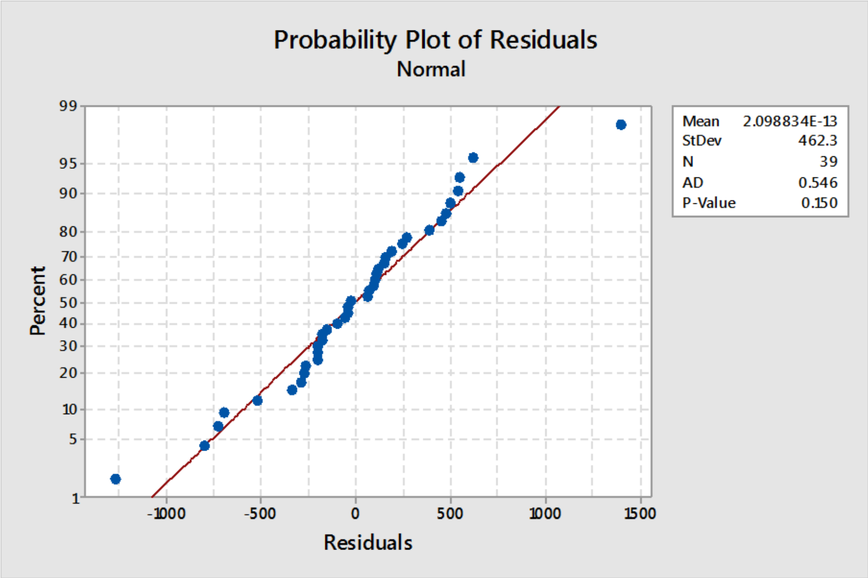

Figure 8.5: Probability plot of data residuals (England)

8.5.2 Test for Equal Variances: Water Use versus Major Sector (England)

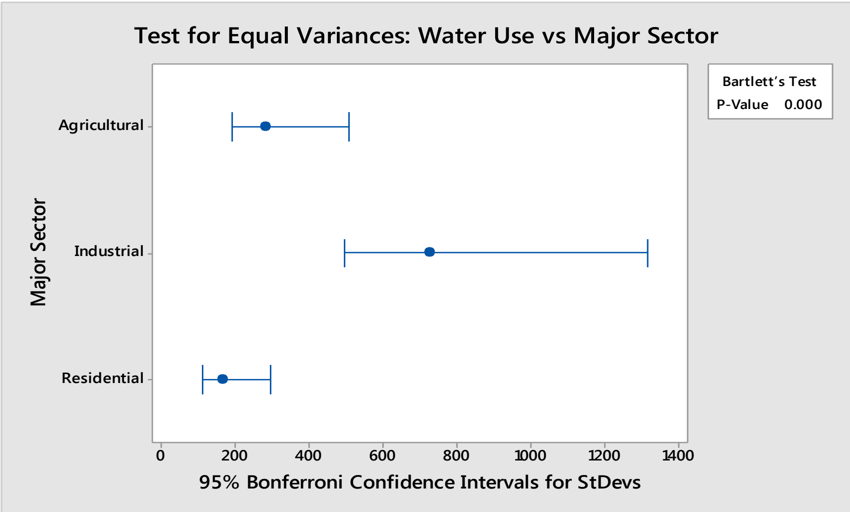

Figure 8.6: Test for Equal Variances: Water Use versus Major Sector (England)

8.5.3 Welch's One-way ANOVA: Water Use versus Major Sector

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Major Sector	3	Agricultural, Industrial, Residential

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Major Sector	2	583551916	291775958	1293.59	0.000
Error	36	8119968	225555		
Total	38	591671884			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
474.926	98.63%	98.55%	98.40%

Means

Major Sector	N	Mean	StDev	95% CI
Agricultural	12	1285.1	294.8	(1007.0, 1563.1)
Industrial	14	10719	725	(10462, 10976)
Residential	13	5375.0	165.5	(5107.9, 5642.1)

Pooled StDev = 474.926

8.5.4 Tukey pairwise comparison of means for water use (England)

Grouping Information Using the Tukey Method and 95% Confidence

Major Sector	N	Mean	Grouping		
Industrial	14	10719	A		
Residential	13	5375.0		B	
Agricultural	12	1285.1			C

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Industrial - Agricultural	9434	187	(8977, 9891)	50.49	0.000
Residential - Agricultural	4090	190	(3625, 4555)	21.51	0.000
Residential - Industrial	-5344	183	(-5791, -4896)	-29.21	0.000

Individual confidence level = 98.06%

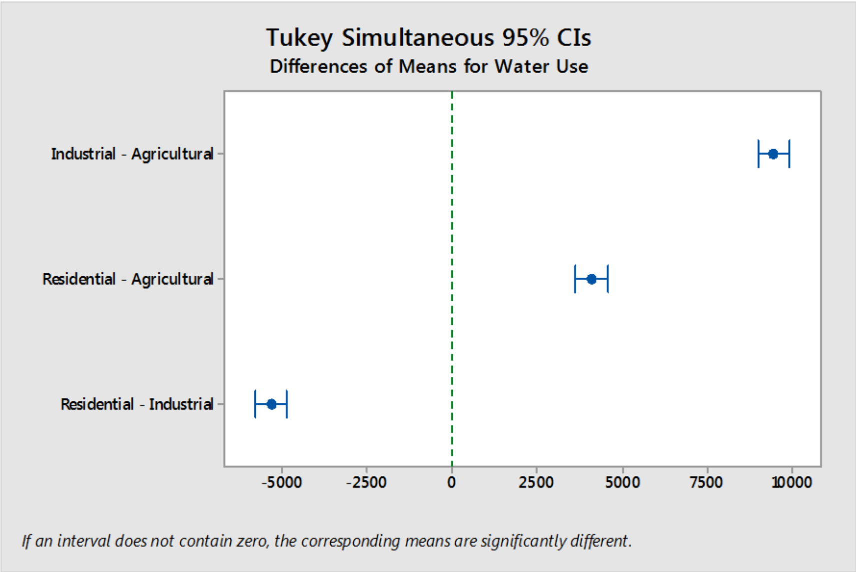

Figure 8.7: Tukey pairwise comparison of means for water use (England)

8.6 Analyses outputs for industrial, domestic and agricultural shares of annual water use in Wales *(Test of Hypothesis 2b)*

8.6.1 Probability plot of Standardized Residuals (Wales)

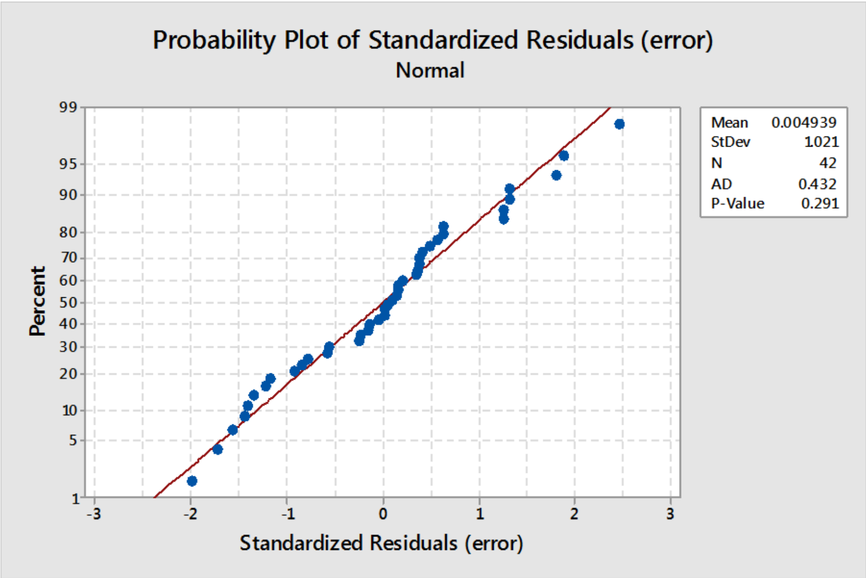

Figure 8.8: Probability plot of Standardized Residuals (Wales)

8.6.2 Test for Equal Variances: Water Use versus Major Sector

```
Method

Null hypothesis         All variances are equal
Alternative hypothesis  At least one variance is different
Significance level      α = 0.05

95% Bonferroni Confidence Intervals for Standard Deviations

Major Sector   N    StDev          CI
Agricultural  14   15.274   ( 11.511,    24.45)
  Industrial  14  978.538   (409.808, 2818.51)
 Residential  14   56.996   ( 33.137,   118.25)
```

```
Individual confidence level = 98.3333%

Tests
                                    Test
Method                      Statistic  P-Value
Multiple comparisons                —    0.000
Levene                           7.54    0.002
```

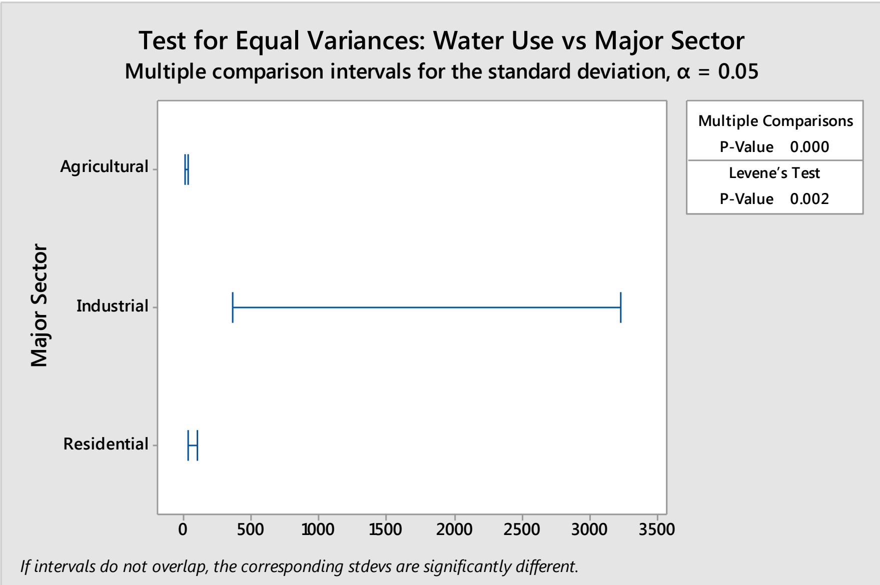

Figure 8.9: Test for Equal Variances: Water Use vs Major Sector (England)

8.6.3 One-way ANOVA: Water Use versus Major Sector

```
Method

Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor        Levels  Values
Major Sector       3  Agricultural, Industrial, Residential

Analysis of Variance

Source        DF   Adj SS   Adj MS  F-Value  P-Value
Major Sector   2  106.317  53.1587  1101.64    0.000
Error         39    1.882   0.0483
Total         41  108.199

Model Summary

       S    R-sq  R-sq(adj)  R-sq(pred)
0.219668  98.26%     98.17%      97.98%

Means

Major Sector   N    Mean   StDev       95% CI
Agricultural  14  4.1198  0.2468  (4.0011, 4.2386)
Industrial    14  7.9832  0.2754  (7.8645, 8.1020)
Residential   14  6.4952  0.0894  (6.3765, 6.6140)

Pooled StDev = 0.219668
```

8.6.4 Tukey pairwise comparison of means for water use (Wales)

```
Grouping Information Using the Tukey Method and 95% Confidence

Major Sector   N    Mean  Grouping
Industrial    14  7.9832  A
Residential   14  6.4952    B
Agricultural  14  4.1198      C

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

                            Difference      SE of                             Adjusted
Difference of Levels          of Means  Difference         95% CI         T-Value  P-Value
Industrial - Agricultural       3.8634      0.0830  ( 3.6608,  4.0659)     46.53    0.000
Residential - Agricultural      2.3754      0.0830  ( 2.1728,  2.5779)     28.61    0.000
Residential - Industrial       -1.4880      0.0830  (-1.6905, -1.2855)    -17.92    0.000

Individual confidence level = 98.06%
```

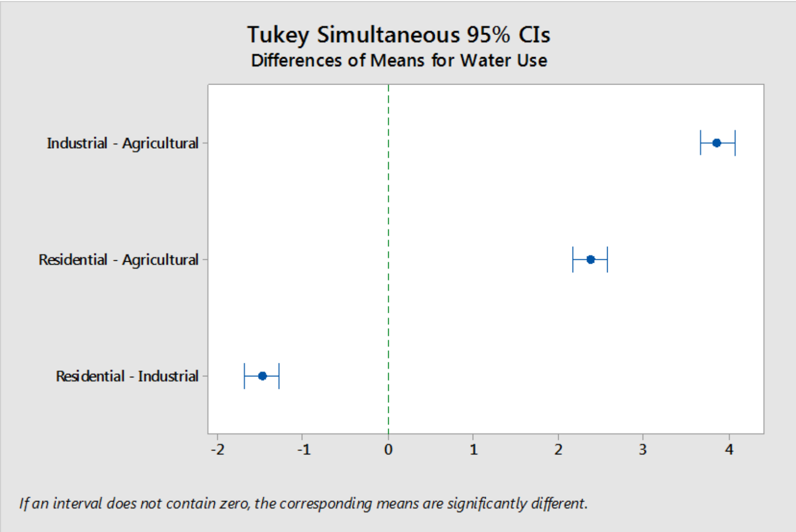

Figure 8.10: Tukey pairwise comparison of means for water use (Wales)

8.7 Analyses outputs for industrial, domestic and agricultural shares of annual water use in Northern Ireland *(Test of Hypothesis 2c)*

8.7.1 Probability plot of data residuals (Northern Ireland)

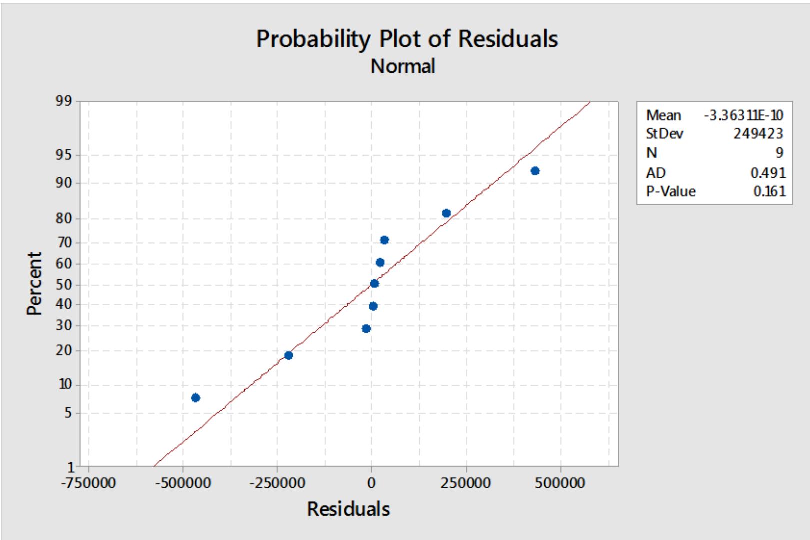

Figure 8.11: Probability plot of data residuals (Northern Ireland)

8.7.2 Test for Equal Variances: Sum of billed water volume (m^3) versus Major Sector

```
Method

Null hypothesis         All variances are equal
Alternative hypothesis  At least one variance is different
Significance level      α = 0.05

Bartlett's method is used. This method is accurate for normal data only.

95% Bonferroni Confidence Intervals for Standard Deviations

 Major Sector  N   StDev            CI
Agriculture    3  452492   (206803, 4946450)
     Industry  3  209616   ( 95801, 2291431)
  Residential  3   12658   (  5785,  138371)

Individual confidence level = 98.3333%

Tests
                Test
Method     Statistic  P-Value
Bartlett       9.79    0.007
```

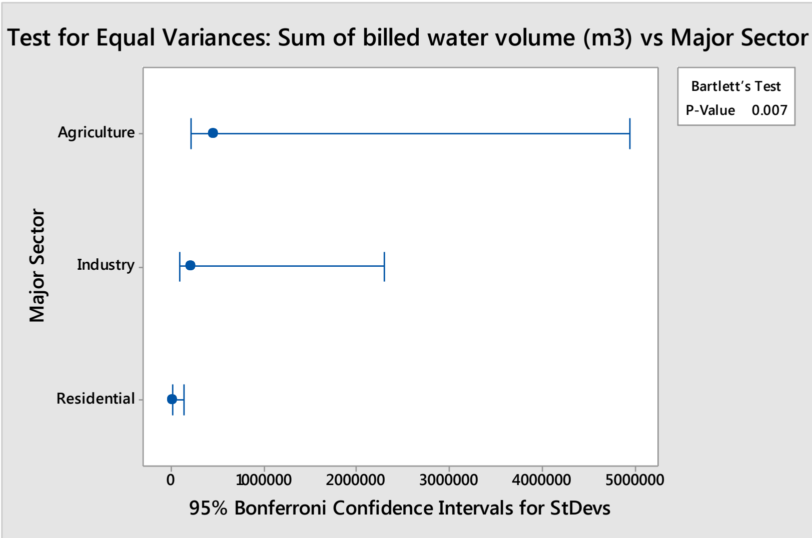

Figure 8.12: Test for Equal Variances: Sum of billed water volume (m3) vs Major Sector (Northern Ireland)

8.7.3 One-way ANOVA: Sum of billed water volume (m^3) versus Major Sector

```
Method

Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor        Levels  Values
Major Sector       3  Agriculture, Industry, Residential

Analysis of Variance

Source        DF       Adj SS       Adj MS  F-Value  P-Value
Major Sector   2  1.66505E+14  8.32524E+13  1003.65    0.000
Error          6  4.97696E+11  82949358339
Total          8  1.67002E+14
```

```
Model Summary

     S    R-sq  R-sq(adj)  R-sq(pred)
288009  99.70%     99.60%      99.33%

Means

Major Sector    N      Mean   StDev           95% CI
Agriculture     3   7993132  452492  (7586254,  8400010)
Industry        3  10172126  209616  (9765248, 10579004)
Residential     3    155627   12658  (-251251,   562505)

Pooled StDev = 288009
```

8.7.4 *Tukey pairwise comparison of means for water use (Northern Ireland)*

```
Grouping Information Using the Tukey Method and 95% Confidence

Major Sector   N      Mean  Grouping
Industry       3  10172126  A
Agriculture    3   7993132    B
Residential    3    155627      C

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

                            Difference       SE of                                     Adjusted
Difference of Levels          of Means  Difference            95% CI          T-Value   P-Value
Industry - Agriculture         2178994      235159  (  1457329,   2900659)     9.27     0.000
Residential - Agriculture     -7837505      235159  ( -8559170, -7115840)    -33.33     0.000
Residential - Industry       -10016499      235159  (-10738164, -9294834)    -42.59     0.000

Individual confidence level = 97.80%
```

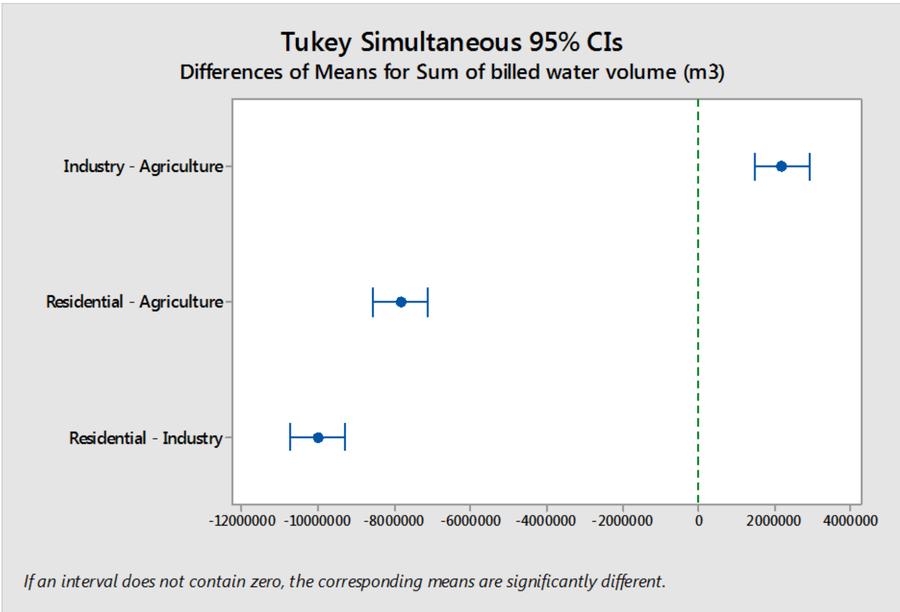

Figure 8.13: Tukey pairwise comparison of means for water use (Northern Ireland)

8.8 Analyses outputs for industrial, domestic and agricultural shares of annual water use in Scotland *(Test of Hypothesis 2d)*

8.8.1 Probability plot of Standardized Residuals (Scotland)

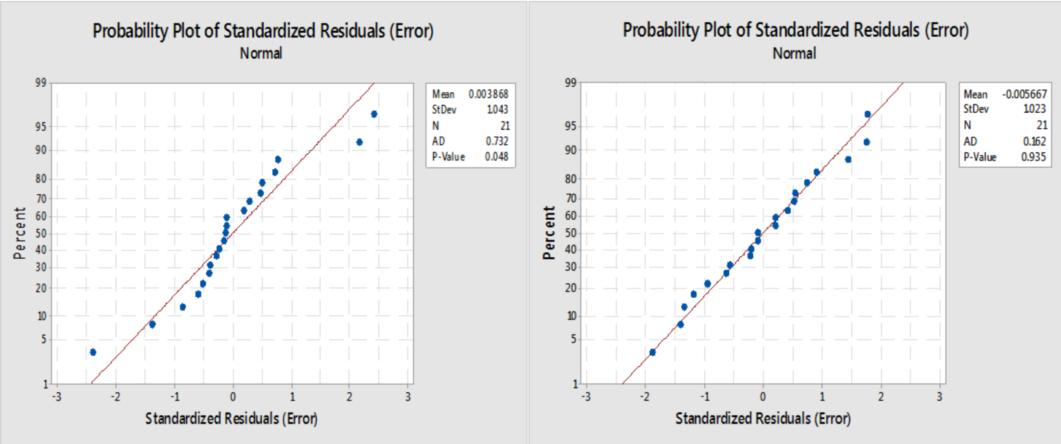

Figure 8.14: Probability plot of Standardized Residuals (Scotland)

8.8.2 Test for Equal Variances: Water Use (Transformed data) vs Major Sector (England)

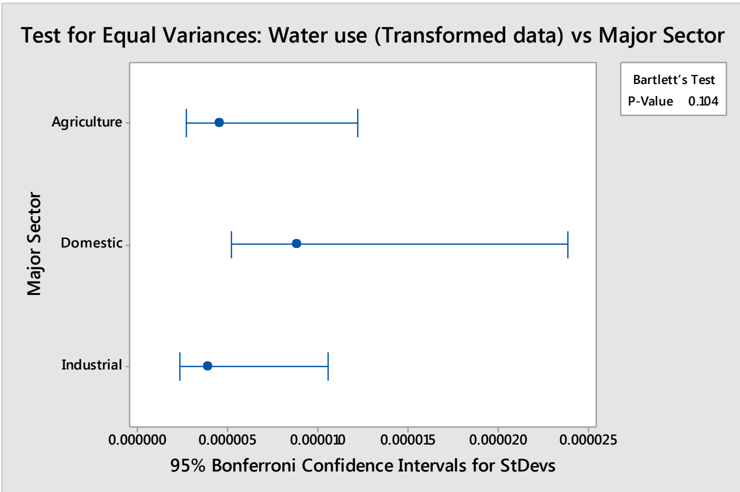

Figure 8.15: Test for Equal Variances: Water Use (Transformed data) vs Major Sector (England)

8.8.3 One-way ANOVA: Water use (Transformed data) versus Major Sector

```
Method

Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor        Levels  Values
Major Sector       3  Agriculture, Domestic, Industrial
```

```
Analysis of Variance

Source         DF    Adj SS    Adj MS  F-Value  P-Value
Major Sector    2  0.000000  0.000000  1530.67    0.000
Error          18  0.000000  0.000000
Total          20  0.000000

Model Summary
        S    R-sq  R-sq(adj)  R-sq(pred)
0.0000061  99.42%     99.35%      99.20%

Means
Major Sector  N      Mean     StDev          95% CI
Agriculture   7  0.000319  0.000004  (0.000314, 0.000324)
Domestic      7  0.000268  0.000009  (0.000263, 0.000273)
Industrial    7  0.000143  0.000004  (0.000139, 0.000148)

Pooled StDev = 6.117166E-06
```

8.8.4 *Tukey pairwise comparison of means for water use (Scotland)*

```
Grouping Information Using the Tukey Method and 95% Confidence

Major Sector  N      Mean  Grouping
Agriculture   7  0.000319  A
Domestic      7  0.000268    B
Industrial    7  0.000143      C

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

                         Difference       SE of                             Adjusted
Difference of Levels       of Means  Difference           95% CI       T-Value   P-Value
Domestic - Agriculture    -0.000051    0.000003  (-0.000060, -0.000043)  -15.67    0.000
Industrial - Agriculture  -0.000176    0.000003  (-0.000184, -0.000168)  -53.79    0.000
Industrial - Domestic     -0.000125    0.000003  (-0.000133, -0.000116)  -38.12    0.000

Individual confidence level = 98.00%
```

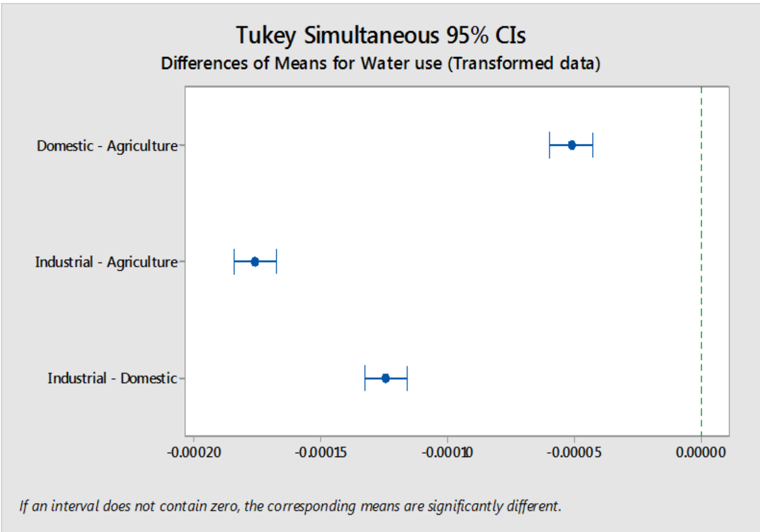

Figure 8.16: Tukey pairwise comparison of means for water use (Scotland)

8.9 Analyses outputs for rates of annual water use (relative to production) by UK Liquid milk production companies *(Test of Hypothesis 3a)*

8.9.1 Johnson Transformation for Liquid milk Water use (L/L)

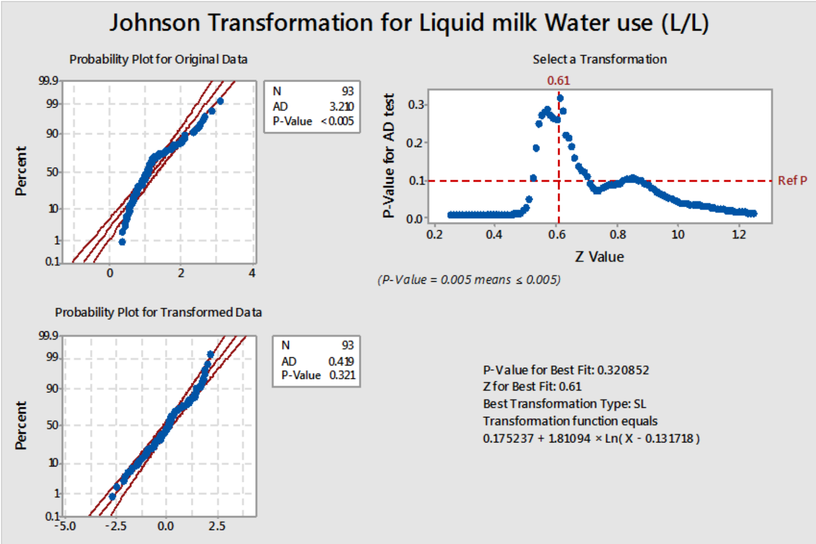

Figure 8.17: Johnson Transformation for Liquid milk Water use (L/L)

8.9.2 Test for Equal Variances: Liquid milk Water use (L/L) versus Site

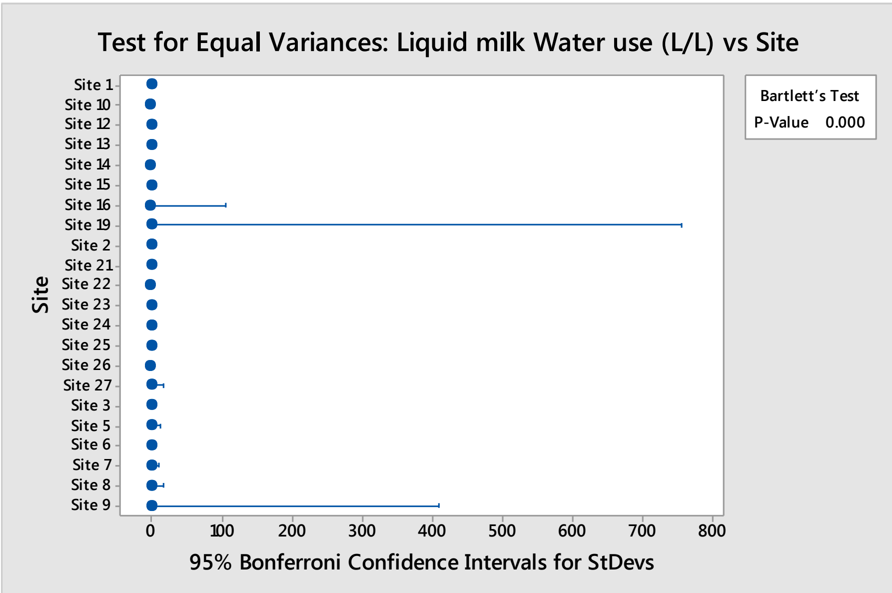

Figure 8.18: Test for Equal Variances: Liquid milk Water use (L/L) versus Site

```
Method

Null hypothesis         All variances are equal
Alternative hypothesis  At least one variance is different
Significance level      α = 0.05

Bartlett's method is used. This method is accurate for normal data only.

95% Bonferroni Confidence Intervals for Standard Deviations

   Site  N    StDev           CI
```

```
 Site 1   4  0.17265  (0.074771,   1.838)
Site 10   5  0.10747  (0.050407,   0.691)
Site 12   5  0.25226  (0.118316,   1.621)
Site 13   5  0.30693  (0.143957,   1.972)
Site 14   5  0.04393  (0.020605,   0.282)
Site 15   4  0.26314  (0.113957,   2.801)
Site 16   2  0.14995  (0.046075, 105.283)
Site 19   2  1.07602  (0.330635, 755.512)
 Site 2   4  0.21952  (0.095067,   2.337)
Site 21   5  0.17724  (0.083131,   1.139)
Site 22   5  0.05791  (0.027161,   0.372)
Site 23   5  1.03560  (0.485720,   6.654)
Site 24   5  0.27286  (0.127977,   1.753)
Site 25   5  0.28468  (0.133523,   1.829)
Site 26   5  0.10983  (0.051514,   0.706)
Site 27   3  0.55870  (0.214570,  16.569)
 Site 3   4  0.21880  (0.094757,   2.329)
 Site 5   3  0.44474  (0.170803,  13.189)
 Site 6   4  0.21032  (0.091084,   2.239)
 Site 7   3  0.34697  (0.133255,  10.290)
 Site 8   3  0.57194  (0.219652,  16.962)
 Site 9   2  0.58348  (0.179291, 409.687)

Individual confidence level = 99.7727%

Tests

                Test
Method     Statistic  P-Value
Bartlett       66.10    0.000
```

8.9.3 One-way ANOVA: Liquid milk Water use (L/L) versus Site

```
Method

Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05
Rows unused             42

Equal variances were assumed for the analysis.

Factor Information

Factor  Levels  Values
Site        27  Site 1, Site 10, Site 11, Site 12, Site 13, Site 14, Site 15, Site 16, Site
                17, Site 18, Site 19, Site 2, Site 20, Site 21, Site 22, Site 23, Site 24,
                Site 25, Site 26, Site 27, Site 3, Site 4, Site 5, Site 6, Site 7, Site 8,
                Site 9

Analysis of Variance

Source  DF   Adj SS  Adj MS  F-Value  P-Value
Site    26   97.736  3.7591    24.96    0.000
Error   66    9.938  0.1506
Total   92  107.674

Model Summary

       S    R-sq  R-sq(adj)  R-sq(pred)
0.388044  90.77%     87.13%           *

Means
Site      N     Mean   StDev        95% CI
Site 1    4   0.4641  0.1727  ( 0.0767,  0.8514)
Site 10   5   0.1753  0.1075  (-0.1712,  0.5218)
Site 11   1   -2.727       *  ( -3.502,  -1.952)
Site 12   5   -0.042   0.252  ( -0.389,   0.304)
Site 13   5    0.687   0.307  (  0.341,   1.034)
Site 14   5  -0.6802  0.0439  (-1.0267, -0.3338)
Site 15   4   -1.356   0.263  ( -1.743,  -0.968)
Site 16   2   -0.893   0.150  ( -1.441,  -0.346)
Site 17   1   -1.464       *  ( -2.239,  -0.690)
Site 18   1  -0.5607       *  (-1.3355,  0.2141)
Site 19   2   -0.699   1.076  ( -1.247,  -0.151)
Site 2    4    0.024   0.220  ( -0.363,   0.412)
Site 20   1    1.751       *  (  0.976,   2.526)
Site 21   5  -0.1859  0.1772  (-0.5324,  0.1606)
Site 22   5   1.3475  0.0579  ( 1.0011,  1.6940)
Site 23   5    1.059   1.036  (  0.713,   1.406)
Site 24   5   -2.086   0.273  ( -2.432,  -1.739)
```

```
Site 25  5    1.300   0.285  (  0.953,   1.646)
Site 26  5   1.7245  0.1098  ( 1.3780,  2.0710)
Site 27  3    0.880   0.559  (  0.433,   1.328)
Site 3   4    0.112   0.219  ( -0.276,   0.499)
Site 4   1  -0.9522       *  (-1.7269, -0.1774)
Site 5   3   -1.029   0.445  ( -1.476,  -0.582)
Site 6   4   -0.056   0.210  ( -0.444,   0.331)
Site 7   3   -0.645   0.347  ( -1.093,  -0.198)
Site 8   3   -0.366   0.572  ( -0.813,   0.082)
Site 9   2   -0.747   0.583  ( -1.295,  -0.199)

Pooled StDev = 0.388044
```

8.9.4 Tukey Pairwise Comparisons

```
Grouping Information Using the Tukey Method and 95% Confidence

Site      N     Mean  Grouping
Site 20  1    1.751  A B C D E F G H I
Site 26  5   1.7245  A
Site 22  5   1.3475  A     D     G
Site 25  5    1.300  A     D     G
Site 23  5    1.059  A B C D E F G H I J
Site 27  3    0.880  A B C D E F G H I J K
Site 13  5    0.687              G H I J K L
Site 1   4   0.4641        D E F G H I J K L M
Site 10  5   0.1753      C     F     I J K L M N
Site 3   4    0.112    B C   E F   H I J K L M N O
Site 2   4    0.024                      K L M N O
Site 12  5   -0.042                      K L M N O
Site 6   4   -0.056                      K L M N O
Site 21  5  -0.1859                      K L M N O
Site 8   3   -0.366                        L M N O P
Site 18  1  -0.5607                  J K L M N O P Q
Site 7   3   -0.645                          M N O P
Site 14  5  -0.6802                            N O P
Site 19  2   -0.699                          M N O P
Site 9   2   -0.747                          M N O P
Site 16  2   -0.893                            N O P Q R
Site 4   1  -0.9522                        L M N O P Q R
Site 5   3   -1.029                              O P Q R
Site 15  4   -1.356                                P Q R
Site 17  1   -1.464                            N O P Q R
Site 24  5   -2.086                                  Q R
Site 11  1   -2.727                                    R

Means that do not share a letter are significantly different.
```

8.10 Analyses outputs for annual water use (relative to production) by UK Cheese production companies *(Test of Hypothesis 3b)*

8.10.1 Probability plot of Standardized Residuals (UK Cheese production)

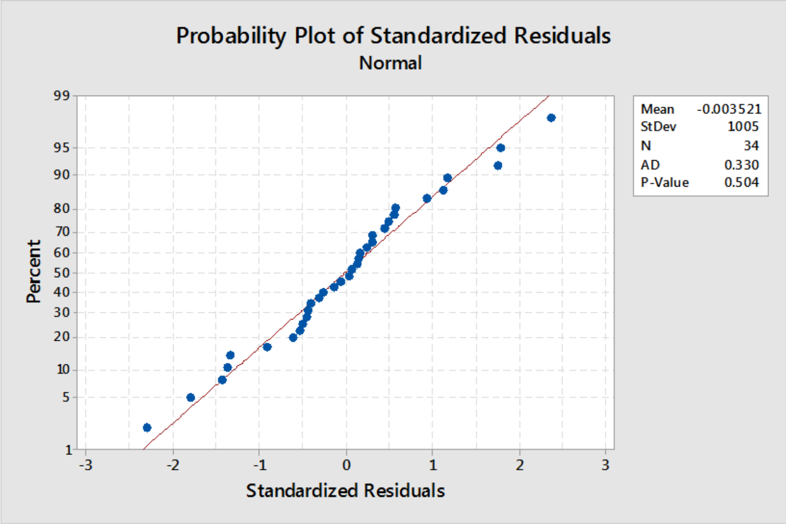

Figure 8.19: Probability plot of Standardized Residuals (UK Cheese production)

8.10.2 Test for Equal Variances: Cheese production Water use-L/L versus Site

```
Method

Null hypothesis         All variances are equal
Alternative hypothesis  At least one variance is different
Significance level      α = 0.05

Bartlett's method is used. This method is accurate for normal data only.

95% Bonferroni Confidence Intervals for Standard Deviations

   Site  N     StDev           CI
 Site 1  2  0.020354  (0.006613,    7.795)
Site 11  3  0.187064  (0.075286,    4.096)
Site 12  3  0.389001  (0.156558,    8.518)
Site 13  3  0.091296  (0.036743,    1.999)
 Site 2  4  0.234439  (0.105878,    2.037)
 Site 3  4  0.116622  (0.052669,    1.013)
 Site 4  2  0.006542  (0.002125,    2.506)
 Site 5  2  0.051186  (0.016629,   19.604)
 Site 6  2  0.415962  (0.135136,  159.307)
 Site 7  2  0.105054  (0.034130,   40.234)
 Site 8  4  0.063614  (0.028729,    0.553)
 Site 9  3  0.535022  (0.215326,   11.716)

Individual confidence level = 99.5833%

Tests
                Test
Method     Statistic  P-Value
Bartlett       23.86    0.013
```

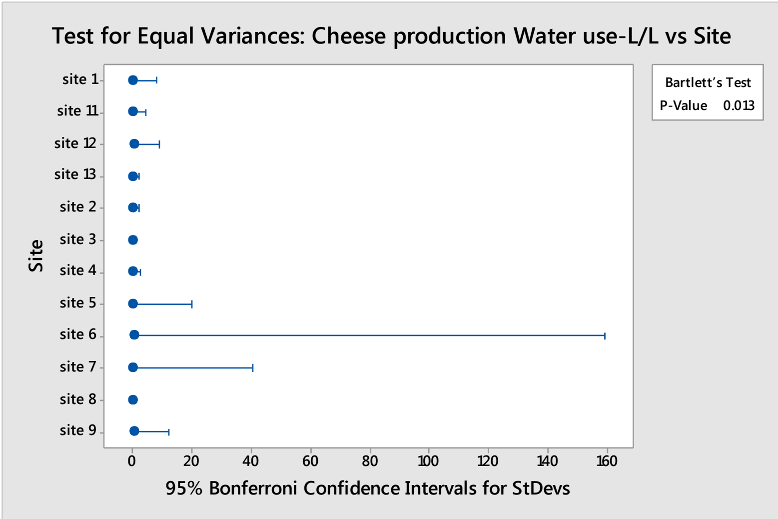

Figure 8.20: Test for Equal Variances: Cheese production Water use-L/L versus Site

8.10.3 One-way ANOVA: Cheese production Water use-L/L versus Site

```
Method

Null hypothesis          All means are equal
Alternative hypothesis   At least one mean is different
Significance level       α = 0.05
Rows unused              30

Equal variances were assumed for the analysis.

Factor Information

Factor  Levels  Values
Site        13  Site 1, Site 10, Site 11, Site 12, Site 13, Site 2, Site 3, Site 4, Site 5,
                Site 6, Site 7, Site 8, Site 9

Analysis of Variance
Source  DF  Adj SS   Adj MS  F-Value  P-Value
Site    12   4.270  0.35580     5.73    0.000
Error   22   1.367  0.06213
Total   34   5.636

Model Summary
       S    R-sq  R-sq(adj)  R-sq(pred)
0.249250  75.75%     62.52%           *

Means

Site     N     Mean    StDev          95% CI
Site 1   2   0.5060   0.0204  (  0.1405,  0.8715)
Site 10  1   0.2974        *  ( -0.2195,  0.8143)
Site 11  3    0.268    0.187  (  -0.030,   0.566)
Site 12  3    0.509    0.389  (   0.211,   0.808)
Site 13  3   0.5805   0.0913  (  0.2820,  0.8789)
Site 2   4    0.319    0.234  (   0.060,   0.577)
Site 3   4   1.4508   0.1166  (  1.1923,  1.7092)
Site 4   2  0.29518  0.00654  (-0.07033, 0.66070)
Site 5   2   0.8739   0.0512  (  0.5084,  1.2394)
Site 6   2    0.438    0.416  (   0.073,   0.804)
Site 7   2   0.7893   0.1051  (  0.4237,  1.1548)
Site 8   4   0.5865   0.0636  (  0.3281,  0.8450)
Site 9   3    0.836    0.535  (   0.537,   1.134)

Pooled StDev = 0.249250
```

8.10.4 Tukey Pairwise Comparisons

```
Grouping Information Using the Tukey Method and 95% Confidence
Site     N    Mean  Grouping
Site 3   4  1.4508  A
Site 5   2  0.8739  A B
Site 9   3   0.836  A B
Site 7   2  0.7893  A B
```

```
Site 8    4   0.5865    B
Site 13   3   0.5805    B
Site 12   3     0.509   B
Site 1    2   0.5060    B
Site 6    2     0.438   B
Site 2    4     0.319   B
Site 10   1   0.2974    B
Site 4    2  0.29518    B
Site 11   3     0.268   B

Means that do not share a letter are significantly different.
```

8.11 Analyses outputs for rates of annual water use (relative to production) by UK Butter production companies *(Test of Hypothesis 3c)*

8.11.1 Johnson Transformation for Water use – Butter (m^3 / tonne)

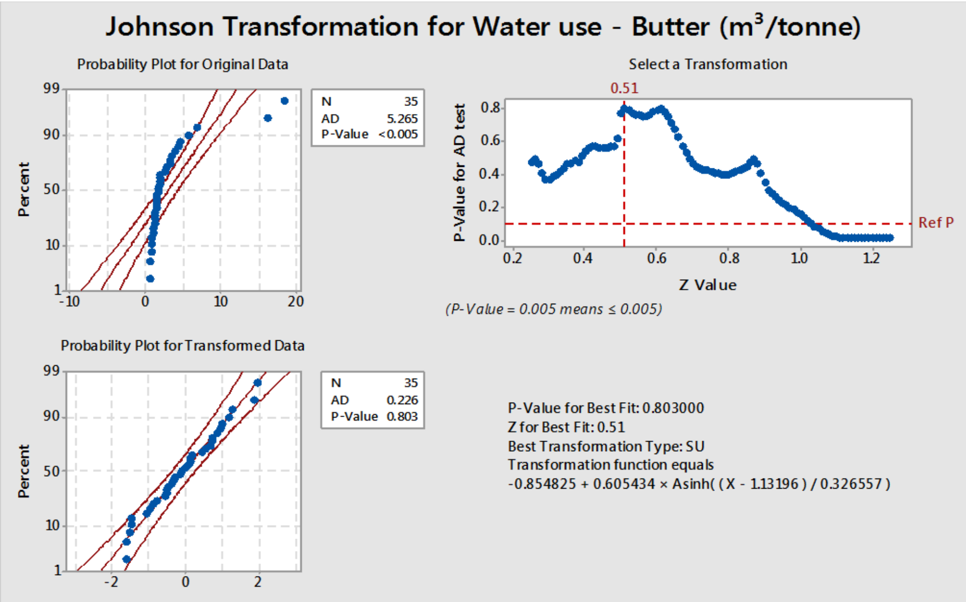

Figure 8.21: Johnson Transformation for Water use – Butter (m^3 / tonne)

8.11.2 Test for Equal Variances: Water use - Butter (m³/tonne) versus Site

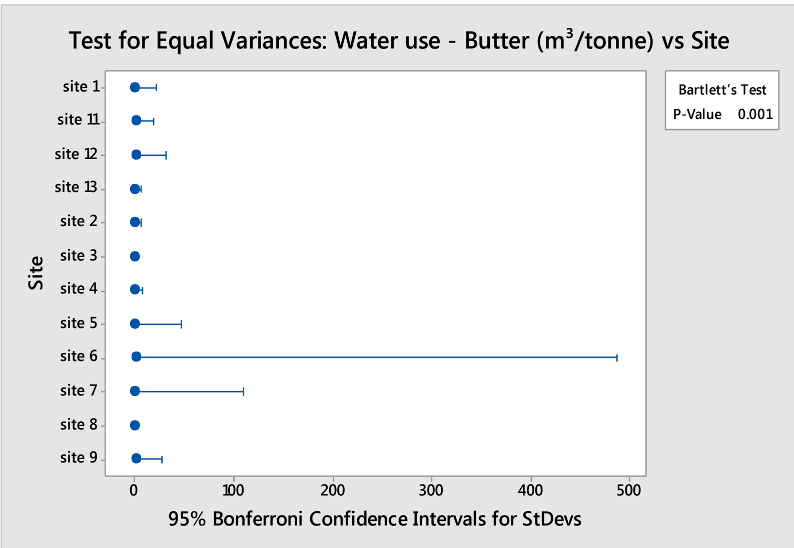

Figure 8.22: Test for Equal Variances: Water use - Butter (m³/tonne) versus Site

Method

Null hypothesis	All variances are equal
Alternative hypothesis	At least one variance is different
Significance level	α = 0.05

Bartlett's method is used. This method is accurate for normal data only.

95% Bonferroni Confidence Intervals for Standard Deviations

Site	N	StDev	CI
Site 1	2	0.05485	(0.017819, 21.006)
Site 11	3	0.86083	(0.346453, 18.850)
Site 12	3	1.38628	(0.557923, 30.356)
Site 13	3	0.25490	(0.102589, 5.582)
Site 2	4	0.68862	(0.310995, 5.982)
Site 3	4	0.05833	(0.026343, 0.507)
Site 4	2	0.02023	(0.006572, 7.747)
Site 5	2	0.12030	(0.039082, 46.073)
Site 6	2	1.27269	(0.413467, 487.419)
Site 7	2	0.28663	(0.093118, 109.773)
Site 8	4	0.17584	(0.079415, 1.528)
Site 9	3	1.24573	(0.501358, 27.278)

Individual confidence level = 99.5833%

Tests

Method	Test Statistic	P-Value
Bartlett	32.04	0.001

8.11.3 One-way ANOVA: Water use - Butter (m^3/tonne) versus Site

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05
Rows unused	30

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Site	13	Site 1, Site 10, Site 11, Site 12, Site 13, Site 2, Site 3, Site 4, Site 5, Site 6, Site 7, Site 8, Site 9

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Site	12	19.74	1.6453	3.07	0.011
Error	22	11.80	0.5366		
Total	34	31.55			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.732511	62.58%	42.17%	*

Means

Site	N	Mean	StDev	95% CI
Site 1	2	0.1220	0.0548	(-0.9522, 1.1962)
Site 11	3	0.973	0.861	(0.096, 1.850)
Site 12	3	0.283	1.386	(-0.594, 1.160)
Site 13	3	-0.084	0.255	(-0.961, 0.793)
Site 2	4	0.694	0.689	(-0.066, 1.454)
Site 3	4	-1.5443	0.0583	(-2.3039, -0.7848)
Site 4	2	0.7116	0.0202	(-0.3626, 1.7858)
Site 5	2	-0.8892	0.1203	(-1.9634, 0.1850)
Site 6	2	0.386	1.273	(-0.688, 1.460)
Site 7	2	-0.666	0.287	(-1.740, 0.408)
Site 8	4	-0.0991	0.1758	(-0.8587, 0.6604)
Site 9	3	-0.558	1.246	(-1.435, 0.319)

Pooled StDev = 0.732511

8.11.4 Tukey Pairwise Comparisons

```
Grouping Information Using the Tukey Method and 95% Confidence

Site     N    Mean   Grouping
Site 11  3    0.973  A
Site 4   2   0.7116  A B
Site 10  1   0.7046  A B
Site 2   4    0.694  A
Site 6   2    0.386  A B
Site 12  3    0.283  A B
Site 1   2   0.1220  A B
Site 13  3   -0.084  A B
Site 8   4  -0.0991  A B
Site 9   3   -0.558  A B
Site 7   2   -0.666  A B
Site 5   2  -0.8892  A B
Site 3   4  -1.5443    B

Means that do not share a letter are significantly different.
```

8.11.5 Johnson Transformation for water use (absolute)

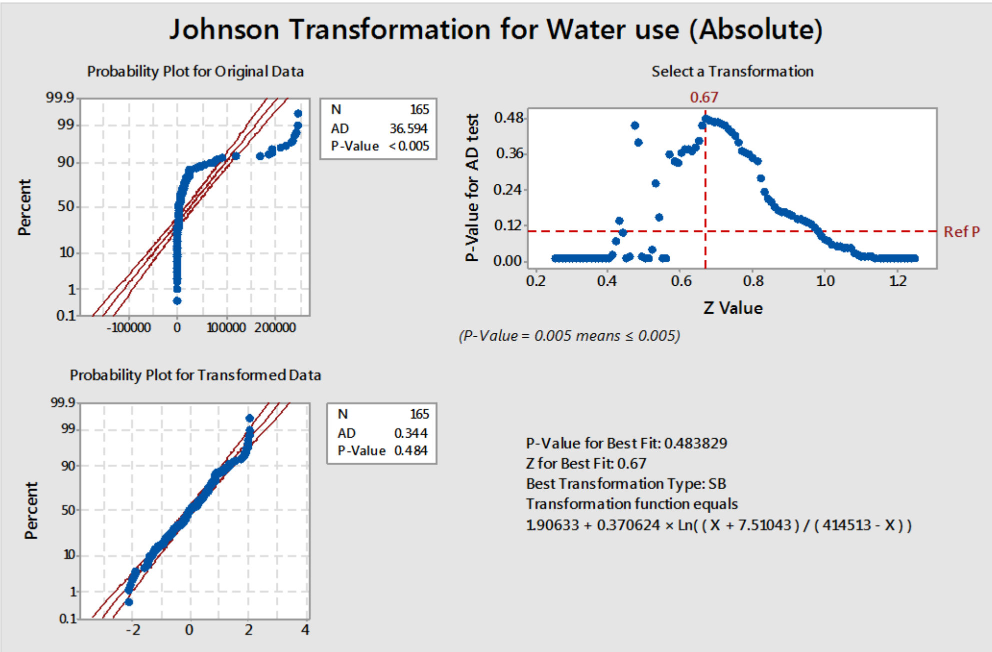

Figure 8.23: Johnson Transformation for water use (absolute)

8.11.6 Test of equality of variances

```
Method

Null hypothesis          All variances are equal
Alternative hypothesis   At least one variance is different
Significance level       α = 0.05

Bartlett's method is used. This method is accurate for normal data only.

95% Bonferroni Confidence Intervals for Standard Deviations

Individual confidence level = 99.875%

Tests

               Test
Method     Statistic  P-Value
Bartlett      566.35    0.000
```

8.11.7 One-way ANOVA: Water use (Absolute) versus Industrial Subsectors

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Industrial Subsectors	39	151.483	3.88417	55.09	0.000
Error	125	8.814	0.07051		
Total	164	160.296			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.265534	94.50%	92.79%	89.66%

Pooled StDev = 0.265534.

8.11.8 Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Industrial Subsectors	Grouping
Miscellaneous manufacturing industries (SIC Code 495)	A B
Processing of fruit and vegetables (SIC Code 414)	A
Manufacture of office machinery and data processing equipment (SIC Code 330)	A B C
Water supply industry (SIC Code 170)	A B C D
Extraction of stone, clay, sand and gravel (SIC Code 231)	B C D
Pharmaceutical products (SIC Code 257)	C D E
Processing of plastics (SIC Code 483)	D E F
Printing and publishing (SIC Code 475)	D E F
Wholesale distribution of timber and building materials (SIC Code 613)	C D E F G H I
Brewing and malting (SIC Code 427)	D E F G
Production and distribution of electricity (SIC Code 161)	D E F G
Bread, biscuits and flour confectionery (SIC Code 419)	D E F G H I
Metal-working machine tools and engineers' tools (SIC Code 322)	D E F G H I
Slaughtering of animals and production of meat and by-products (SIC Code 412)	D E F G H I J
Miscellaneous foods (SIC Code 423)	E F G H I J K
Rubber products (SIC Code 481)	E F G H I J K
Industrial plant and steelwork (SIC Code 320)	F G H I J K L
Public gas supply (SIC Code 162)	F G H I J K L M
Machinery for the food, chemical and related industries, etc. (SIC Code 324)	F G H I J K L M N O
Working of stone & other non-metallic minerals not elsewhere specified (SIC 245)	G I J K L M
Wholesale distribution of pharmaceutical, medical & other chemists' goods (618)	H I J K L M
Ice cream, cocoa, chocolate and sugar confectionery (SIC Code 421)	J K L M N O P
Wholesale distribution of textiles, clothing, footwear & leather goods (SIC 616)	K L M N O P
Electric lamps and other electric lighting equipment (SIC Code 347)	K L M N O P
Non-ferrous metals industry (SIC Code 224)	J K L M N O P Q R
Miscellaneous textiles (SIC Code 439)	L M N O P Q
Paints, varnishes and printing ink (SIC Code 255)	M N O P Q R
Extraction of mineral oil and natural gas (SIC Code 130)	M N O P Q R
Soft drinks (SIC Code 428)	M N O P Q R S
Basic industrial chemicals (SIC Code 251)	O P Q R S
Iron and steel industry (SIC Code 221)	N O P Q R S
Specialised chemical products mainly for industrial & agric purposes (SIC 256)	P Q R S
Textile finishing (SIC Code 437)	Q R S T
Cotton and silk industries (SIC Code 432)	Q R S T
Manufacture, processing & treatmentof semi-finished wood products (SIC Code 462)	P Q R S T
Production of man-made fibres (SIC Code 260)	R S T U
Preparation of milk and milk products (SIC Code 413)	Q R S T U
Nuclear fuel production & distribution of electricity, gas, etc. (SIC Code 152)	S T U
Production and distribution of other forms of energy (SIC Code 163)	T U
Pulp, paper and board (SIC Code 471)	U

Means that do not share a letter are significantly different.

8.12 Analyses outputs for energy consumption rates of major UK industrial processes *(Test of Hypothesis 6)*

8.12.1 Johnson Transformation for Energy Use per Unit product

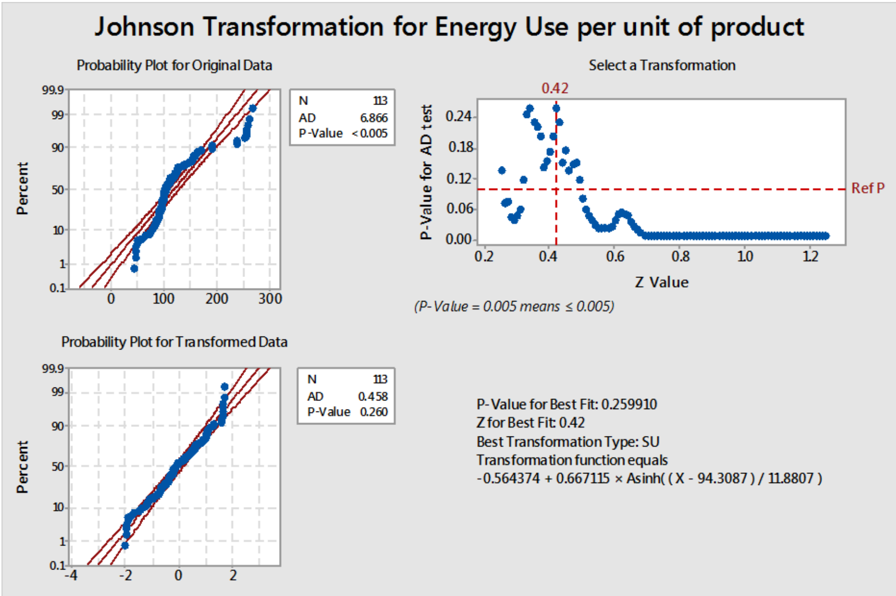

Figure 8.24: Johnson Transformation for Energy Use per Unit product

8.12.2 Correlation: Year, Iron & Steel, Chemicals, Food, drink & tobacco, All industry

	Year	Iron & Steel	Chemicals	Food, drink & tobacco
Iron & Steel	-0.890 0.000			
Chemicals	-0.944 0.000	0.922 0.000		
Food, drink & tobacco	-0.967 0.000	0.933 0.000	0.916 0.000	
All industry	-0.943 0.000	0.982 0.000	0.936 0.000	0.970 0.000

```
Cell Contents: Pearson correlation
               P-Value
```

8.12.3 Regression Analysis: Energy Use per unit of product versus Year, Industrial Sector

Method

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	7	97.615	13.9450	234.61	0.000
Year	1	19.365	19.3645	325.78	0.000
Industrial Sector	3	11.402	3.8007	63.94	0.000
Year*Industrial Sector	3	11.436	3.8120	64.13	0.000
Error	105	6.241	0.0594		
Total	112	103.856			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)

```
0.243804  93.99%     93.59%      93.20%

Coefficients

Term                           Coef  SE Coef  T-Value  P-Value       VIF
Constant                     158.56     8.78    18.06    0.000
Year                       -0.07942  0.00440   -18.05    0.000      4.85
Industrial Sector
  Chemicals                    70.7     11.6     6.10    0.000  48672.99
  Food, drink & tobacco       -27.7     12.3    -2.25    0.027  49754.96
  Iron & Steel                -71.9     11.4    -6.31    0.000  49091.92
Year*Industrial Sector
  Chemicals                -0.03561  0.00581    -6.13    0.000  48645.81
  Food, drink & tobacco     0.01376  0.00618     2.23    0.028  49752.48
  Iron & Steel              0.03598  0.00571     6.30    0.000  49090.03

Regression Equation

Industrial Sector
All industry           Energy Use per unit of product = 158.56 - 0.07942 Year

Chemicals              Energy Use per unit of product = 229.24 - 0.11504 Year

Food, drink & tobacco  Energy Use per unit of product = 130.83 - 0.06566 Year

Iron & Steel           Energy Use per unit of product = 86.70 - 0.04344 Year


Fits and Diagnostics for Unusual Observations

     Energy Use
       per unit
Obs  of product     Fit    Resid  Std Resid
 57     -0.7747  0.0903  -0.8651      -3.61  R
104     -0.7261  0.2054  -0.9315      -3.89  R

R  Large residual
```

9.0 Appendix B

9.1 Benchmarking Software procedures

9.1.1 ThisWorkbook (i-Water Benchmarking Tool.xlsm)

ThisWorkbook (i-Water Benchmarking Tool.xlsm) VBAProject

```
Option Explicit
Private Sub Workbook_NewSheet(ByVal Sh As Object)

  With Application
    .ScreenUpdating = False
    .DisplayAlerts = False

    ActiveSheet.Delete

    MsgBox "User is not permitted to add a New Sheet!" & vbCrLf & _
    "Please use buttons on the Home page." , vbCritical + vbOKOnly, "Err Msg"

    .DisplayAlerts = True
    .ScreenUpdating = True
  End With

End Sub
Private Sub Workbook_Open()

  Sheets("About the i-Water Tool" ).Visible = xlVeryHidden
  Sheets("Terms of Use" ).Visible = xlVeryHidden
  Sheets("Database" ).Visible = xlVeryHidden
  Sheets("Data Entry Sheet" ).Visible = xlVeryHidden
  Sheets("Data Entry Sheet." ).Visible = xlVeryHidden
  Sheets("Data input and Validation" ).Visible = xlVeryHidden
  Sheets("Benchmarking results" ).Visible = xlVeryHidden

  Worksheets("Benchmarking results" ).Range("Y1:BF49" ).Value = ""
  Worksheets("Benchmarking results" ).Range("Y1:BF49" ).Font.Color = RGB(0, 32, 96)
  Worksheets("Benchmarking results" ).Range("Y1:BF49" ).Interior.Color = vbWhite

  frm_Tool_Operation.Show
  Dim ws As Worksheet

  For Each ws In Application.ActiveWorkbook.Worksheets
    ws.scrollarea = ws.Usedrange.Address
    If Sheet1.scrollarea = Sheet1.Usedrange.Address = True Then
    End If
    Exit Sub
  Next

End Sub
```

9.1.2 Sheet1 (Home page)

Sheet1 (Home page) VBAProject

```
Option Explicit
Private Sub Worksheet_Activate()
  Me.scrollarea = Range(Me.Usedrange, Me.Usedrange(2, 2)).Address
  If Sheet1.scrollarea = Sheet1.Usedrange.Address = True Then
  End If
End Sub
```

9.1.3 Sheet3 (Terms of Use)

Sheet3 (Terms of Use) VBAProject

```
Option Explicit
Private Sub Worksheet_Activate()
  Me.scrollarea = Range(Me.Usedrange, Me.Usedrange(2, 2)).Address
  If Sheet1.scrollarea = Sheet3.Usedrange.Address = True Then
  End If
End Sub
```

9.1.4 Sheet8 (Benchmarking results)

Sheet8 (Benchmarking results) VBAProject

```
Option Explicit

Private Sub Worksheet_Activate()

  'Restore Content (e.g. Company Name:, Date:, etc.)

  Range("A6" ).Value = "Benchmarking Date:"
  Range("G6" ).Value = "Company Name:"
  Range("G12" ).Value = "Country:"
  Range("G11" ).Value = "State:"
  Range("G7" ).Value = "Branch/Site:"
  Range("G8" ).Value = "Company Address:"
  Range("A9" ).Value = "Company category:"
  Range("G9" ).Value = "Zip/Post Code:"
  Range("A7" ).Value = "Benchmarking Staff:"
  Range("G10" ).Value = "Telephone:"
  Range("J13" ).Value = "Notes"
  Range("A10" ).Value = "Industrial Sector:"
  Range("A11" ).Value = "Division:"
  Range("A12" ).Value = "Segment:"
  Range("A13" ).Value = "Production Process:"
  Range("A14" ).Value = "KPI:"
  Range("A15" ).Value = "Benchmarking Unit:"
  Range("M27" ).Value = "Site"
  Range("N27" ).Value = "Average water"
  Range("N28" ).Value = "use/unit Product"
  Range("Q27" ).Value = "Benchmark"
  Range("Q28" ).Value = "(Lower)"
  Range("T27" ).Value = "Deviation"
  Range("T28" ).Value = "about Benchmark"
  Range("U27" ).Value = "Deviation"
  Range("U28" ).Value = "Value (%)"
  Range("V27" ).Value = "Water"
  Range("V28" ).Value = "charges (£)"
  Range("W27" ).Value = "Wastewater"
  Range("W28" ).Value = "charges (£)"
  Range("P27" ).Value = "Rank"
  Range("P28" ).Value = "1 = Highest"

  If INDUSTRIAL_SECTOR <> ""  Then
    Range("D10" ).Value = INDUSTRIAL_SECTOR 'Industrial Sector
    Range("D11" ).Value = DIV_SEL 'Division
    Range("D12" ).Value = SEG_SEL 'Segment
    Range("D13" ).Value = PROC_SEL 'Production Process
    Range("D14" ).Value = KPI 'KPI
    Range("D15" ).Value = BENCHMARK_UNIT 'Benchmarking Unit
  End If

End Sub
```

9.1.5 frm_FieldSpecify2

frm_FieldSpecify2 VBAProject

```
Option Explicit
Public Site01_Col As Long
Public Site02_Col As Long

Public PeriodB_Col As Long
Public PeriodA_Col As Long

Private Sub cmdEndPeriod_Click()

    txtEndPeriod.Text = ActiveCell.Value
    txtEndPeriod.Tag = ActiveCell.Row
    PeriodB_Col = ActiveCell.Column
End Sub

Private Sub cmdOK_Click()

    Dim n As Long
    Dim m As Long

    Dim j As Long
    Dim k As Long

    Dim Period_Data() As String
    Dim Period_Date() As String

    Dim Destination_Start_Title_Row As Long
    Dim Destination_Start_Title_Col As Long

    Dim Destination_Row_Cnt As Long

    Dim SiteNumber_Source As String


    'Copy the Data from 'Data Entry Sheet' to 'Data input and Validation'

    On Error GoTo ErrHandler:

    Destination_Start_Title_Row = 11
    Destination_Start_Title_Col = 1


    'Do error checking first...
    If CheckValidPeriod(txtStartPeriod) = False Or _
        CheckValidPeriod(txtEndPeriod) = False Then

        MsgBox "The period you've specified seems to be invalid..." & vbCrLf & _
        "Please check that it follows any of the following formats: " & vbCrLf & _
        "19##, 19##-##, 20##, 20##-##, ... OR Jan,Feb,...Dec OR " & vbCrLf & _
        "January,February,...December OR " & vbCrLf & _
        "January/February, March/April, ... November/December OR" & vbCrLf & _
        "Jan/Feb, Mar/Apr, ... Nov/Dec OR" & vbCrLf & _
        "January-February, March-April, ... November-December OR" & vbCrLf & _
        "Jan-Feb, Mar-Apr, ... Nov-Dec OR" , vbOKOnly + vbInformation, "Warning!"

        Exit Sub
    End If

    If Val(txtStartPeriod.Tag) > Val(txtEndPeriod.Tag) Then
        MsgBox "The start period appears to be greater than the end period." & vbCrLf &
        _

        "Please check this and try again" , vbOKOnly + vbInformation, "Warning"
        txtStartPeriod.Value = ""
        txtEndPeriod.Value = ""
        Exit Sub
    End If

    If Val(Site01_Col) > Val(Site02_Col) Then
        MsgBox "The start site appears to be greater than the last site." & vbCrLf & _
        "Please check this and try again" , vbOKOnly + vbInformation, "Warning"
        txtSiteStart.Value = ""
        txtSiteLast.Value = ""
        Exit Sub
    End If
```

```
If Val(PeriodB_Col) <> Val(PeriodA_Col) Then
    MsgBox "The start period and end period were not on the same column" & vbCrLf &
    _
    "Please check this and try again" , vbOKOnly + vbInformation, "Warning"
    txtStartPeriod.Value = ""
    txtEndPeriod.Value = ""
    Exit Sub
End If

If Val(PeriodA_Col) = Site01_Col Or _
    Val(PeriodB_Col) = Site02_Col Then
    MsgBox "The start site appears to be incorrect (i.e. lines up with the period
    COLUMN)" & vbCrLf & _
    "Please check this and try again" , vbOKOnly + vbInformation, "Warning"
    txtSiteStart.Value = ""
    txtSiteLast.Value = ""
    Exit Sub
End If

If Val(txtSiteStart.Tag) <> 2 Or _
    Val(txtSiteLast.Tag) <> 2 Then
    MsgBox "The first and/or last site selection appears to be outside the valid
    row" & vbCrLf & _
    "Please check and make sure the selection made is under row 2 only!" , vbOKOnly +
     vbInformation, "Warning"
    txtSiteStart.Value = ""
    txtSiteLast.Value = ""
    Exit Sub
End If

If Val(PeriodA_Col) <> 1 Or _
    Val(PeriodB_Col) <> 1 Then
    MsgBox "The first and/or last period selection appears to be outside the valid
    column" & vbCrLf & _
    "Please check and make sure the selection made is under column A only!" ,
    vbOKOnly + vbInformation, "Warning"
    txtStartPeriod.Value = ""
    txtEndPeriod.Value = ""
    Exit Sub
End If

'txtStartPeriod.Tag 'Column Number for the Start of Period
'txtEndPeriod.Tag 'Column Number for the End of Period
Application.ScreenUpdating = False
Application.Interactive = False


Destination_Row_Cnt = Destination_Start_Title_Row

ReDim Period_Data(txtEndPeriod.Tag - txtStartPeriod.Tag)
ReDim Period_Date(txtEndPeriod.Tag - txtStartPeriod.Tag)

For n = Site01_Col To Site02_Col '2 To Columns.Count
    'Make sure we start at 'Data Entry Sheet'
    Sheets("Data Entry Sheet." ).Select

    If IsEmpty(Cells(2, n).Value) = True Then Exit For

    'Read Site Number
    SiteNumber_Source = Cells(Val(txtSiteStart.Tag), n).Value

    'Read First to Last Date Data
    For m = 0 To (txtEndPeriod.Tag - txtStartPeriod.Tag)
        Period_Data(m) = CStr(Cells(Val(txtStartPeriod.Tag) + m, n).Value)
        Period_Date(m) = CStr(Cells(Val(txtStartPeriod.Tag) + m, 1).Value)
    Next m

    'Jump over to 'Data input and Validation'
    Sheets("Data input and Validation" ).Visible = True
    Sheets("Data input and Validation" ).Select

    'Clear entries (if existing)
    Dim row_l As Long
    Dim col_l As Long
```

```
            If n = Site01_Col Then                            'clear entries on first loop
              'Data and Site
              For row_l = 12 To Rows.Count
                If IsEmpty(Cells(row_l, 1).Value) = True Then Exit For
                For col_l = 1 To 21                         'Columns.Count
                  Cells(row_l, col_l).Value = ""          'clear entry on that cell
                Next col_l
              Next row_l

              'Year/Period
              For col_l = 2 To 21 'Columns.Count
                Cells(11, col_l).Value = ""                 'clear entry on that cell
              Next col_l
            End If

            Destination_Row_Cnt = Destination_Row_Cnt + 1
            Cells(Destination_Row_Cnt, 1).Value = SiteNumber_Source

            'Update the Dates/Data...
            k = 0
            For j = 2 To 2 + (txtEndPeriod.Tag - txtStartPeriod.Tag)
              Cells(Destination_Start_Title_Row, j).Value = Period_Date(k)
              'The Date on the title
              If Len(Period_Data(k)) = 0 Or Period_Data(k) = "-"  Then
                Cells(Destination_Row_Cnt, j).Value = ""
                'Period Data
              Else
                Cells(Destination_Row_Cnt, j).Value = Format(Period_Data(k), "0.0000" )
                'Period Data
              End If
              'Cells(Destination_Row_Cnt, j).Select
              'Selection.NumberFormat = "0.0000"

              k = k + 1
            Next j
          Next n

          Application.ScreenUpdating = True
          Application.Interactive = True

          Me.Hide

          Exit Sub

          ErrHandler:
          Application.ScreenUpdating = True
          Application.Interactive = True
          txtStartPeriod.Value = ""
          txtEndPeriod.Value = ""
          txtSiteStart.Value = ""
          txtSiteLast.Value = ""

          MsgBox "You have either made an invalid selection, or not populated the four
          textboxes, "  & vbCrLf & _
          "or not provided valid descriptions for the period. "  & vbCrLf & _
          "Please follow the direction on the Specify Field form "  & vbCrLf & _
          "and ensure that your period descriptions are in the following formats: "  & vbCrLf
          & _
          "19##, 19##-##, 20##, 20##-##, ... OR Jan,Feb,...Dec OR "  & vbCrLf & _
          "January,February,...December OR "  & vbCrLf & _
          "January/February, March/April, ... November/December OR"  & vbCrLf & _
          "Jan/Feb, Mar/Apr, ... Nov/Dec OR"  & vbCrLf & _
          "January-February, March-April, ... November-December OR"  & vbCrLf & _
          "Jan-Feb, Mar-Apr, ... Nov-Dec OR" , vbOKOnly + vbInformation, "Warning!"

        End Sub
```

```
Private Sub cmdSelSiteLast_Click()
    txtSiteLast.Text = ActiveCell.Value
    txtSiteLast.Tag = ActiveCell.Row
    Site02_Col = ActiveCell.Column
End Sub

Private Sub cmdSelSiteStart_Click()

    txtSiteStart.Text = ActiveCell.Value
    txtSiteStart.Tag = ActiveCell.Row
    Site01_Col = ActiveCell.Column

End Sub

Private Sub cmdStrtPeriod_Click()

    txtStartPeriod.Text = ActiveCell.Value
    txtStartPeriod.Tag = ActiveCell.Row
    PeriodA_Col = ActiveCell.Column

End Sub

Private Sub UserForm_Activate()

    Sheets("Data Entry Sheet." ).Select

1
1
    'Start with clean / empty data on text boxes...
    txtStartPeriod.Text = ""
    txtEndPeriod.Text = ""
    txtSiteStart.Text = ""
    txtSiteLast.Text = ""

    'Lock from user
    txtStartPeriod.Locked = True
    txtEndPeriod.Locked = True
    txtSiteStart.Locked = True
    txtSiteLast.Locked = True

End Sub
```

9.1.6 frm_DataSampleFormat2

frm_DataSampleFormat2 VBAProject

```
Option Explicit

Private Sub Show_Data_Entry_Sheet_Click()

    Dim ActiveView As String

    Application.ScreenUpdating = False
    Application.Interactive = False
    Worksheets("Home page" ).Visible = True

    ActiveView = ActiveSheet.Name

    Worksheets("Data Input and Validation" ).Visible = xlVeryHidden

    FORMAT_SELECTED = 2

    Worksheets("Data input and validation" ).Activate
    Range("a1" ).Select
    Unload Me
    MsgBox "Thanks"  & vbCrLf & "Now click on the Input Data tab" , vbOKOnly +
    vbInformation, "Information"
    Worksheets("Data Input and Validation" ).Visible = xlVeryHidden
    frm_Benchmarking_Specifics.Show

    Application.ScreenUpdating = True
    Application.Interactive = True

End Sub
```

```
Private Sub Show_DataSampleFormat1_Click()
    Unload Me
    frm_DataSampleFormat1.Show
End Sub

Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)
    If CloseMode = 0 Then
        Cancel = True
        MsgBox "X is disabled on this form!"  & vbCrLf & "Please click on any other
        tab." , vbCritical
    End If
End Sub
```

9.1.7 Frm_Process_Assessment

Frm_Process_Assessment VBAProject

```
Option Explicit

Dim count_of_1 As Integer
Dim count_of_2 As Integer
Dim count_of_3 As Integer
Dim count_of_4 As Integer
Dim count_of_5 As Integer

'CheckBoxes
Private Sub CheckBox1_Click()
    If CheckBox1 = True Then
        CheckBox2 = False
    End If
    Call UserForm111_Click
End Sub

Private Sub CheckBox10_click()
    If CheckBox10 = True Then
        TextBox1002.Text = ""
        TextBox1002.Enabled = False
        TextBox1002.BackColor = vbYellow
        CheckBox11 = False
        CheckBox12 = False
        CheckBox13 = False
        CheckBox14 = False
    Else
        TextBox1002.Enabled = True
        TextBox1002.BackColor = vbWhite
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox100_click()
    If CheckBox100 = True Then
        TextBox1007.Enabled = True
        TextBox1007.BackColor = vbWhite
        CheckBox96 = False
        CheckBox97 = False
        CheckBox98 = False
        CheckBox99 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox101_click()
    If CheckBox101 = True Then
        CheckBox102 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox102_click()
    If CheckBox102 = True Then
        CheckBox101 = False
    End If
```

```
    Call UserForm111_Click
End Sub

Private Sub CheckBox103_click()
    If CheckBox103 = True Then
        CheckBox104 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox104_click()
    If CheckBox104 = True Then
        CheckBox103 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox105_click()
    If CheckBox105 = True Then
        CheckBox106 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox106_click()
    If CheckBox106 = True Then
        CheckBox105 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox107_click()
    If CheckBox107 = True Then
        CheckBox108 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox108_click()
    If CheckBox108 = True Then
        CheckBox107 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox109_click()
    If CheckBox109 = True Then
        CheckBox110 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox11_click()
```

```
    Call UserForm111_Click
End Sub

Private Sub CheckBox103_click()
    If CheckBox103 = True Then
        CheckBox104 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox104_click()
    If CheckBox104 = True Then
        CheckBox103 = False
    End If

    Call UserForm111_Click
End Sub
```

```
Private Sub CheckBox105_click()
    If CheckBox105 = True Then
        CheckBox106 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox106_click()
    If CheckBox106 = True Then
        CheckBox105 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox107_click()
    If CheckBox107 = True Then
        CheckBox108 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox108_click()
    If CheckBox108 = True Then
        CheckBox107 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox109_click()
    If CheckBox109 = True Then
        CheckBox110 = False
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox11_click()

    If CheckBox11 = True Then
        TextBox1002.Text = ""
        TextBox1002.Enabled = False
        TextBox1002.BackColor = vbYellow
        CheckBox10 = False
        CheckBox12 = False
        CheckBox13 = False
        CheckBox14 = False
    Else
        TextBox1002.Enabled = True
        TextBox1002.BackColor = vbWhite
    End If

    Call UserForm111_Click
End Sub

Private Sub CheckBox15_click()
    If CheckBox15 = True Then
        CheckBox16 = False
    End If
    Call UserForm111_Click
End Sub

Private Sub CheckBox16_click()
    If CheckBox16 = True Then
        CheckBox15 = False
    End If
    Call UserForm111_Click
End Sub
```

```
what form are these stored?"
Range("AL35" ).Value = "Staff education and awareness"
Range("AK36" ).Value = "34. Do you currently have water conservation education or
awareness programmes for staff /"
Range("AL37" ).Value = "employees in your organisation?"
Range("AK38" ).Value = "35. Are water conservation notices or information displayed
at common meeting areas"
Range("AL39" ).Value = "(e.g. restaurants), restrooms, strategic locations or
points of water use?"
Range("AK40" ).Value = "36. Are there incentives to recognise or reward sites or
departments with the best (optimal)"
Range("AL41" ).Value = "water use, relative to others?"
Range("AK42" ).Value = "37. Do you currently have water conservation suggestion
'Question 1
If Me.CheckBox1.Value = True Then
  Range("AH8" ).Value = "Yes"
Else
  Range("AH8" ).Value = ""
  If Me.CheckBox2.Value = True Then
    Range("AH8" ).Value = "No"
  Else
    Range("AH8" ).Value = ""
  End If
End If

'Question 1a
If Me.CheckBox3 = True Then
  Range("AC9" ).Value = "Monthly"
Else
  Range("AC9" ).Value = ""

  If Me.CheckBox4 = True Then
    Range("AC9" ).Value = "Quarterly"
  Else
    Range("AC9" ).Value = ""

    If Me.CheckBox5 = True Then
      Range("AC9" ).Value = "Half-Yearly"
    Else
      Range("AC9" ).Value = ""

      If Me.CheckBox6 = True Then
        Range("AC9" ).Value = "Yearly"
      Else
        Range("AC9" ).Value = ""

        If Me.CheckBox7 = True Then
          Range("AC9" ).Value = "Others:"
          Range("AD9" ).Value = TextBox1001.Value
        Else
          Range("AC9" ).Value = ""
          Range("AD9" ).Value = ""

        End If
      End If
    End If
  End If
End If

'Question 2
If Me.CheckBox8.Value = True Then
  Range("AJ10" ).Value = "Yes"
Else
  Range("AJ10" ).Value = ""
  If Me.CheckBox9.Value = True Then
    Range("AJ10" ).Value = "No"
  Else
    Range("AJ10" ).Value = ""
  End If
End If
```

```
'Question 2a
If Me.CheckBox10 = True Then
  Range("AC11" ).Value = "Monthly"
Else
  Range("AC11" ).Value = ""

  If Me.CheckBox11 = True Then
    Range("AC11" ).Value = "Quarterly"
  Else
    Range("AC11" ).Value = ""

    If Me.CheckBox12 = True Then
      Range("AC11" ).Value = "Half-Yearly"
    Else
      Range("AC11" ).Value = ""

      If Me.CheckBox13 = True Then
        Range("AC11" ).Value = "Yearly"
      Else
        Range("AC11" ).Value = ""

        If Me.CheckBox14 = True Then
          Range("AC11" ).Value = "Others:"
          Range("AD11" ).Value = TextBox1002.Value
        Else
          Range("AC11" ).Value = ""
          Range("AD11" ).Value = ""

        End If
      End If
    End If
  End If
End If

'Question 3
If Me.CheckBox15.Value = True Then
  Range("AD13" ).Value = "Yes"
Else
1 2
1 2
  Range("AD13" ).Value = ""
  If Me.CheckBox16.Value = True Then
    Range("AD13" ).Value = "No"
  Else
    Range("AD13" ).Value = ""
  End If
End If

'Question 4
If Me.CheckBox17.Value = True Then
  Range("AH14" ).Value = "Yes"
Else
  Range("AH14" ).Value = ""
  If Me.CheckBox18.Value = True Then
    Range("AH14" ).Value = "No"
  Else
    Range("AH14" ).Value = ""
  End If
End If

'Question 4a
If Me.CheckBox19 = True Then
  Range("AD15" ).Value = "Monthly"
Else
  Range("AD15" ).Value = ""

  If Me.CheckBox20 = True Then
    Range("AD15" ).Value = "Quarterly"
  Else
    Range("AD15" ).Value = ""

    If Me.CheckBox21 = True Then
      Range("AD15" ).Value = "Half-Yearly"
    Else
      Range("AD15" ).Value = ""
```

```
                If Me.CheckBox22 = True Then
                    Range("AD15" ).Value = "Yearly"
                Else
                    Range("AD15" ).Value = ""

                    If Me.CheckBox23 = True Then
                        Range("AD15" ).Value = "Others:"
                        Range("AE15" ).Value = TextBox1003.Value
                    Else
                        Range("AD15" ).Value = ""
                        Range("AE15" ).Value = ""

                    End If
                End If
            End If
        End If
    End If

    'Question 5
    If Me.CheckBox24.Value = True Then
        Range("AE17" ).Value = "Yes"
    Else
        Range("AE17" ).Value = ""
        If Me.CheckBox25.Value = True Then
1 2 3
1 2 3
            Range("AE17" ).Value = "No"
        Else
            Range("AE17" ).Value = ""
        End If
    End If

    'Question 6
    If Me.CheckBox26.Value = True Then
        Range("AF19" ).Value = "Yes"
    Else
        Range("AF19" ).Value = ""
        If Me.CheckBox27.Value = True Then
            Range("AF19" ).Value = "No"
        Else
            Range("AF19" ).Value = ""

            If Me.CheckBox28.Value = True Then
                Range("AF19" ).Value = "N.A."
            Else
                Range("AF19" ).Value = ""
            End If
        End If
    End If
    'Question 7
    If Me.CheckBox29.Value = True Then
        Range("AH20" ).Value = "Yes"
    Else
        Range("AH20" ).Value = ""
        If Me.CheckBox30.Value = True Then
            Range("AH20" ).Value = "No"
        Else
            Range("AH20" ).Value = ""
        End If
    End If

    'Question 8
    Range("Y24" ).Value = ChrW(10007)
    Range("Y25" ).Value = ChrW(10007)
    Range("Y26" ).Value = ChrW(10007)
    Range("Y27" ).Value = ChrW(10007)
    Range("Y28" ).Value = ChrW(10007)

    If Me.CheckBox31 = True Then
        Range("Z24" ).Interior.Color = RGB(217, 217, 217)
        Range("Y24" ).Value = ChrW(10003)
        Range("Y24" ).Font.Bold = True
        Range("Z24:AB24" ).Font.Bold = True

    Else
        Range("Z24" ).Interior.Color = vbWhite
        Range("Y24" ).Font.Bold = False
        Range("Z24:AB24" ).Font.Bold = False
    End If
```

```
If Me.CheckBox32 = True Then
    Range("Z25" ).Interior.Color = RGB(217, 217, 217)
    Range("Y25" ).Value = ChrW(10003)
    Range("Y25" ).Font.Bold = True
    Range("Z25:AC25" ).Font.Bold = True

Else
    Range("Z25" ).Interior.Color = vbWhite
    Range("Y25" ).Font.Bold = False
    Range("Z25:AC25" ).Font.Bold = False
End If

If Me.CheckBox33 = True Then
    Range("Z26" ).Interior.Color = RGB(217, 217, 217)
    Range("Y26" ).Value = ChrW(10003)
    Range("Y26" ).Font.Bold = True
    Range("Z26:AF26" ).Font.Bold = True

Else
    Range("Z26" ).Interior.Color = vbWhite
    Range("Y26" ).Font.Bold = False
    Range("Z26:AF26" ).Font.Bold = False
End If

If Me.CheckBox34 = True Then
    Range("Z27" ).Interior.Color = RGB(217, 217, 217)
    Range("Y27" ).Value = ChrW(10003)
    Range("Y27" ).Font.Bold = True
    Range("Z27:AA27" ).Font.Bold = True
Else
    Range("Z27" ).Interior.Color = vbWhite
    Range("Y27" ).Font.Bold = False
    Range("Z27:AA27" ).Font.Bold = False
End If
If Me.CheckBox35 = True Then
    Range("Z28" ).Interior.Color = RGB(217, 217, 217)
    Range("Y28" ).Value = ChrW(10003)
    Range("Y28" ).Font.Bold = True

    Range("Z28" ).Font.Bold = True

    Range("AA28" ).Value = TextBox1004.Value
    Range("AA28" ).Interior.Color = RGB(217, 217, 217)
    Range("AA28" ).Font.Bold = True

Else
    Range("AA28" ).Interior.Color = vbWhite
    Range("Z28" ).Interior.Color = vbWhite

    Range("Y28" ).Font.Bold = False
    Range("Z28" ).Font.Bold = False
    Range("AA28" ).Font.Bold = False

End If
'Question 9

If Me.CheckBox36 = True Then
    Range("AG29" ).Value = "Cyclical flushing type"
Else
    Range("AG29" ).Value = ""

    If Me.CheckBox37 = True Then
        Range("AG29" ).Value = "Occupancy detector type"
    Else

        Range("AG29" ).Value = ""

        If Me.CheckBox38 = True Then
            Range("AG29" ).Value = "Motion sensor flush type"
        Else
            Range("AG29" ).Value = ""
        End If
    End If
End If
```

```
'Question 10

If Me.CheckBox39 = True Then
  Range("AD30" ).Value = "Manually"
Else
  Range("AD30" ).Value = ""

  If Me.CheckBox40 = True Then
    Range("AD30" ).Value = "Automatic closure"
  Else
    Range("AD30" ).Value = ""

    If Me.CheckBox41 = True Then
      Range("AD30" ).Value = "Sensor activated"
    Else
      Range("AD30" ).Value = ""

    End If
  End If
End If

'Question 11
If Me.CheckBox42.Value = True Then
  Range("AF32" ).Value = "Yes"
Else
  Range("AF32" ).Value = ""
  If Me.CheckBox43.Value = True Then
    Range("AF32" ).Value = "No"
  Else
    Range("AF32" ).Value = ""
  End If
End If

'Question 12
If Me.CheckBox44.Value = True Then
  Range("AA34" ).Value = "Yes"
Else
  Range("AA34" ).Value = ""
  If Me.CheckBox45.Value = True Then
    Range("AA34" ).Value = "No"
  Else
    Range("AA34" ).Value = ""
  End If
End If
1 2
  If Me.CheckBox47.Value = True Then
    Range("AF35" ).Value = "No"
  Else
    Range("AF35" ).Value = ""
  End If
End If

'Question 13a
If Me.CheckBox48 = True Then
  Range("AE36" ).Value = "Monthly"
Else
  Range("AE36" ).Value = ""

  If Me.CheckBox49 = True Then
    Range("AE36" ).Value = "Quarterly"
  Else
    Range("AE36" ).Value = ""

    If Me.CheckBox50 = True Then
      Range("AE36" ).Value = "Half-Yearly"
    Else
      Range("AE36" ).Value = ""

      If Me.CheckBox51 = True Then
        Range("AE36" ).Value = "Yearly"
      Else
        Range("AE36" ).Value = ""
```

```
                    If Me.CheckBox52 = True Then
                        Range("AE36" ).Value = "Others:"
                        Range("AF36" ).Value = TextBox1005.Value
                    Else
                        Range("AE36" ).Value = ""
                        Range("AF36" ).Value = ""

                    End If
                End If
            End If
        End If
    End If

    'Question 14
    If Me.CheckBox53.Value = True Then
        Range("AF38" ).Value = "Yes"
    Else
        Range("AF38" ).Value = ""
        If Me.CheckBox54.Value = True Then
            Range("AF38" ).Value = "No"
        Else
            Range("AF38" ).Value = ""
        End If
    End If

    'Question 15
    If Me.CheckBox55 = True Then
        Range("Z40" ).Value = "Water"
    Else
        Range("Z40" ).Value = ""


        If Me.CheckBox56 = True Then
            Range("Z40" ).Value = "Air"
        Else
            Range("Z40" ).Value = ""

            If Me.CheckBox57 = True Then
                Range("Z40" ).Value = "Other means excluding water"
            Else
                Range("Z40" ).Value = ""

                If Me.CheckBox58 = True Then
                    Range("Z40" ).Value = "Combination of methods"
                Else
                    Range("Z40" ).Value = ""

                End If
            End If
        End If
    End If

    'Question 16
    If Me.CheckBox59.Value = True Then
        Range("AH41" ).Value = "Yes"
    Else
        Range("AH41" ).Value = ""
        If Me.CheckBox60.Value = True Then
            Range("AH41" ).Value = "No"
        Else
            Range("AH41" ).Value = ""
        End If
    End If

    'Question 17
    If Me.CheckBox61.Value = True Then
        Range("AI42" ).Value = "Yes"
    Else
        Range("AI42" ).Value = ""
        If Me.CheckBox62.Value = True Then
            Range("AI42" ).Value = "No"
        Else
            Range("AI42" ).Value = ""
        End If
    End If
```

```
'Question 18
If Me.CheckBox63.Value = True Then
    Range("AJ43" ).Value = "Yes"
Else
    Range("AJ43" ).Value = ""
    If Me.CheckBox64.Value = True Then
        Range("AJ43" ).Value = "No"
    Else
        Range("AJ43" ).Value = ""
    End If
End If

'Question 19
If Me.CheckBox65.Value = True Then
    Range("AE46" ).Value = "Yes"
Else
    Range("AE46" ).Value = ""
    If Me.CheckBox66.Value = True Then
        Range("AE46" ).Value = "No"
    Else
        Range("AE46" ).Value = ""
    End If
End If

'Question 20
If Me.CheckBox67 = True Then
    Range("Z48" ).Value = "Monthly"
Else
    Range("Z48" ).Value = ""

    If Me.CheckBox68 = True Then
        Range("Z48" ).Value = "Quarterly"
    Else
        Range("Z48" ).Value = ""

        If Me.CheckBox69 = True Then
            Range("Z48" ).Value = "Half-Yearly"
        Else
            Range("Z48" ).Value = ""

            If Me.CheckBox70 = True Then
                Range("Z48" ).Value = "Yearly"
            Else
                Range("Z48" ).Value = ""

                If Me.CheckBox71 = True Then
                    Range("Z48" ).Value = "Others:"
                    Range("AA48" ).Value = TextBox1006.Value
                Else
                    Range("Z48" ).Value = ""
                    Range("AA48" ).Value = ""

                End If
            End If
        End If
    End If
End If

'Question 21
If Me.CheckBox72 = True Then
    Range("AD49" ).Value = "Manually"
Else
    Range("AD49" ).Value = ""

    If Me.CheckBox73 = True Then
        Range("AD49" ).Value = "Using automatic leak detectors"
    Else
        Range("AD49" ).Value = ""
    End If
End If

'Question 21a

If Me.CheckBox74.Value = True Then
    Range("AT4" ).Value = "Yes"
```

```
'Question 21
If Me.CheckBox72 = True Then
    Range("AD49" ).Value = "Manually"
Else
    Range("AD49" ).Value = ""

    If Me.CheckBox73 = True Then
        Range("AD49" ).Value = "Using automatic leak detectors"
    Else
        Range("AD49" ).Value = ""
    End If
End If

'Question 21a

If Me.CheckBox74.Value = True Then
    Range("AT4" ).Value = "Yes"
1 2
1 2
Else
    Range("AT4" ).Value = ""
    If Me.CheckBox75.Value = True Then
        Range("AT4" ).Value = "No"
    Else
        Range("AT4" ).Value = ""
    End If
End If

'Question 22
If Me.CheckBox76.Value = True Then
    Range("AP6" ).Value = "Yes"
Else
    Range("AP6" ).Value = ""
    If Me.CheckBox77.Value = True Then
        Range("AP6" ).Value = "No"
    Else
        Range("AP6" ).Value = ""
    End If
End If

'Question 23
If Me.CheckBox78.Value = True Then
    Range("AS11" ).Value = "Yes"
Else
    Range("AS11" ).Value = ""
    If Me.CheckBox79.Value = True Then
        Range("AS11" ).Value = "No"
    Else
        Range("AS11" ).Value = ""
    End If
End If

'Question 24
If Me.CheckBox80.Value = True Then
    Range("AV12" ).Value = "Yes"
Else
    Range("AV12" ).Value = ""
    If Me.CheckBox81.Value = True Then
        Range("AV12" ).Value = "No"
    Else
        Range("AV12" ).Value = ""
    End If
End If

'Question 25
If Me.CheckBox82.Value = True Then
    Range("AL17" ).Value = "Yes"
Else
    Range("AL17" ).Value = ""
    If Me.CheckBox83.Value = True Then
        Range("AL17" ).Value = "No"
    Else
        Range("AL17" ).Value = ""
    End If
End If

'Question 26
If Me.CheckBox84.Value = True Then
    Range("AO20" ).Value = "Yes"
1 2
```

```
    Else
        Range("AO20" ).Value = ""
        If Me.CheckBox85.Value = True Then
            Range("AO20" ).Value = "No"
        Else
            Range("AO20" ).Value = ""
        End If
    End If

    'Question 27
    If Me.CheckBox86.Value = True Then
        Range("AT22" ).Value = "Yes"
    Else
        Range("AT22" ).Value = ""
        If Me.CheckBox87.Value = True Then
            Range("AT22" ).Value = "No"
        Else
            Range("AT22" ).Value = ""
        End If
    End If

    'Question 28
    If Me.CheckBox88.Value = True Then
        Range("AN24" ).Value = "Yes"
    Else
        Range("AN24" ).Value = ""
        If Me.CheckBox89.Value = True Then
            Range("AN24" ).Value = "No"
        Else
            Range("AN24" ).Value = ""
        End If
    End If
    'Question 29
    If Me.CheckBox90.Value = True Then
        Range("AV25" ).Value = "Yes"
    Else
        Range("AV25" ).Value = ""
        If Me.CheckBox91.Value = True Then
            Range("AV25" ).Value = "No"
        Else
            Range("AV25" ).Value = ""
        End If
    End If

    'Question 30
    If Me.CheckBox92.Value = True Then
        Range("AO27" ).Value = "Yes"
    Else
        Range("AO27" ).Value = ""
        If Me.CheckBox93.Value = True Then
            Range("AO27" ).Value = "No"
        Else
            Range("AO27" ).Value = ""
        End If
    End If

    'Question 31
    If Me.CheckBox94.Value = True Then
        Range("AS28" ).Value = "Yes"
    Else
        Range("AS28" ).Value = ""
        If Me.CheckBox95.Value = True Then
            Range("AS28" ).Value = "No"
        Else
            Range("AS28" ).Value = ""
        End If
    End If

    'Question 31a
    If Me.CheckBox96 = True Then
        Range("AP29" ).Value = "Monthly"
    Else
        Range("AP29" ).Value = ""

        If Me.CheckBox97 = True Then
            Range("AQ29" ).Value = "Quarterly"
        Else
            Range("AP29" ).Value = ""
```

```
            If Me.CheckBox98 = True Then
               Range("AP29" ).Value = "Half-Yearly"
            Else
               Range("AP29" ).Value = ""

               If Me.CheckBox99 = True Then
                  Range("AP29" ).Value = "Yearly"
               Else
                  Range("AP29" ).Value = ""

                  If Me.CheckBox100 = True Then
                     Range("AP29" ).Value = "Others:"
                     Range("AQ29" ).Value = TextBox1006.Value
                  Else
                     Range("AP29" ).Value = ""
                     Range("AQ29" ).Value = ""

                  End If
               End If
            End If
         End If
      End If
      'Question 32
      If Me.CheckBox101.Value = True Then
         Range("AR31" ).Value = "Yes"
      Else
         Range("AR31" ).Value = ""
         If Me.CheckBox102.Value = True Then
            Range("AR31" ).Value = "No"
         Else
            Range("AR31" ).Value = ""
         End If
      End If

      'Question 33
      If Me.CheckBox103.Value = True Then
         Range("AL33" ).Value = "Water use per unit product"
      Else
1 2
1 2
         Range("AL33" ).Value = ""
         If Me.CheckBox104.Value = True Then
            Range("AL33" ).Value = "Total water use per period"
         Else
            Range("AL33" ).Value = ""
         End If
      End If

      'Question 34
      If Me.CheckBox105.Value = True Then
         Range("AP37" ).Value = "Yes"
      Else
         Range("AP37" ).Value = ""
         If Me.CheckBox106.Value = True Then
            Range("AP37" ).Value = "No"
         Else
            Range("AP37" ).Value = ""
         End If
      End If
      'Question 35
      If Me.CheckBox107.Value = True Then
         Range("AT39" ).Value = "Yes"
      Else
         Range("AT39" ).Value = ""
         If Me.CheckBox108.Value = True Then
            Range("AT39" ).Value = "No"
         Else
            Range("AT39" ).Value = ""
         End If
      End If

      'Question 36
      If Me.CheckBox109.Value = True Then
         Range("AP41" ).Value = "Yes"
      Else
         Range("AP41" ).Value = ""
         If Me.CheckBox110.Value = True Then
            Range("AP41" ).Value = "No"
         Else
            Range("AP41" ).Value = ""
         End If
      End If
```

```
    'Question 37
    If Me.CheckBox111.Value = True Then
        Range("AO43" ).Value = "Yes"
    Else
        Range("AO43" ).Value = ""
        If Me.CheckBox112.Value = True Then
            Range("AO43" ).Value = "No"
        Else
            Range("AO43" ).Value = ""
        End If
    End If

    'Question 38
    If Me.CheckBox113.Value = True Then
        Range("AQ45" ).Value = "Yes"
    Else
1 2
1 2
        Range("AQ45" ).Value = ""
        If Me.CheckBox114.Value = True Then
            Range("AQ45" ).Value = "No"
        Else
            Range("AQ45" ).Value = ""
        End If
    End If

    'Question 39
    If Me.CheckBox115.Value = True Then
        Range("AR47" ).Value = "Yes"
    Else
        Range("AR47" ).Value = ""
        If Me.CheckBox116.Value = True Then
            Range("AR47" ).Value = "No"
        Else
            Range("AR47" ).Value = ""
        End If
    End If

    'Question 40
    If Me.CheckBox117.Value = True Then
        Range("AV48" ).Value = "High"
    Else
        Range("AV48" ).Value = ""

        If Me.CheckBox118.Value = True Then
            Range("AV48" ).Value = "Average"
        Else
            Range("AV48" ).Value = ""

            If Me.CheckBox119.Value = True Then
                Range("AV48" ).Value = "Low"
            Else
                Range("AV48" ).Value = ""

                If Me.CheckBox120.Value = True Then
                    Range("AV48" ).Value = "N.A."
                Else
                    Range("AV48" ).Value = ""

                End If
            End If
        End If
    End If

    Application.ScreenUpdating = True
    Application.Interactive = True

    Unload Me
End Sub

Private Sub TextBox1001_Change()
    If TextBox1001.Value <> ""  Then

        Me.CheckBox7.Value = True
    Else
        Me.CheckBox7.Value = False
    End If
1
```

```
End Sub

Private Sub TextBox1002_Change()
If TextBox1002.Value <> "" Then

Me.CheckBox14.Value = True
Else
Me.CheckBox14.Value = False
End If
End Sub

Private Sub TextBox1003_Change()
If TextBox1003.Value <> "" Then

Me.CheckBox23.Value = True
Else
Me.CheckBox23.Value = False
End If
End Sub

Private Sub TextBox1004_Change()
If TextBox1004.Value <> "" Then

Me.CheckBox35.Value = True
Else
Me.CheckBox35.Value = False
End If
End Sub

Private Sub TextBox1005_Change()
If TextBox1005.Value <> "" Then

Me.CheckBox52.Value = True
Else
Me.CheckBox52.Value = False
End If
End Sub

Private Sub TextBox1006_Change()
If TextBox1006.Value <> "" Then

Me.CheckBox71.Value = True
Else
Me.CheckBox71.Value = False
End If
End Sub

Private Sub TextBox1007_Change()
If TextBox1007.Value <> "" Then

Me.CheckBox100.Value = True
Else
Me.CheckBox100.Value = False
End If
End Sub

Private Sub UserForm_Activate()

Sheets("Benchmarking results").Select


If Range("AH8").Value = "Yes" Then

CheckBox1.Value = True
CheckBox2.Value = False
ElseIf Range("AH8").Value = "No" Then
CheckBox1.Value = False
CheckBox2.Value = True

End If

If Range("AC9").Value = "Monthly" Then

CheckBox3.Value = True
CheckBox4.Value = False
CheckBox5.Value = False
CheckBox6.Value = False
CheckBox7.Value = False
```

```
    ElseIf Range("AC9" ).Value = "Quarterly"  Then

        CheckBox3.Value = False
        CheckBox4.Value = True
        CheckBox5.Value = False
        CheckBox6.Value = False
        CheckBox7.Value = False

    ElseIf Range("AC9" ).Value = "Half-Yearly"  Then

        CheckBox3.Value = False
        CheckBox4.Value = False
        CheckBox5.Value = True
        CheckBox6.Value = False
        CheckBox7.Value = False

    ElseIf Range("AC9" ).Value = "Yearly"  Then

        CheckBox3.Value = False
        CheckBox4.Value = False
        CheckBox5.Value = False
        CheckBox6.Value = True
        CheckBox7.Value = False

    ElseIf Range("AC9" ).Value = "Others:"  Then

        CheckBox3.Value = False
        CheckBox4.Value = False
        CheckBox5.Value = False
        CheckBox6.Value = False
        CheckBox7.Value = True

    End If

    TextBox1001.Value = Range("AD9" ).Value

    If Range("AJ10" ).Value = "Yes"  Then

        CheckBox8.Value = True
        CheckBox9.Value = False
    ElseIf Range("AJ10" ).Value = "No"  Then

        CheckBox8.Value = False
        CheckBox9.Value = True

    End If

    If Range("AC11" ).Value = "Monthly"  Then

        CheckBox10.Value = True
        CheckBox11.Value = False
        CheckBox12.Value = False
        CheckBox13.Value = False
        CheckBox14.Value = False

    ElseIf Range("AC11" ).Value = "Quarterly"  Then

        CheckBox10.Value = False
        CheckBox11.Value = True
        CheckBox12.Value = False
        CheckBox13.Value = False
        CheckBox14.Value = False

    ElseIf Range("AC11" ).Value = "Half-Yearly"  Then

        CheckBox10.Value = False
        CheckBox11.Value = False
        CheckBox12.Value = True
        CheckBox13.Value = False
        CheckBox14.Value = False

    ElseIf Range("AC11" ).Value = "Yearly"  Then

        CheckBox10.Value = False
        CheckBox11.Value = False
        CheckBox12.Value = False
        CheckBox13.Value = True
        CheckBox14.Value = False
```

```
ElseIf Range("AC11" ).Value = "Others:"  Then

    CheckBox10.Value = False
    CheckBox11.Value = False
    CheckBox12.Value = False
    CheckBox13.Value = False
    CheckBox14.Value = True
End If

TextBox1002.Value = Range("AD11" ).Value

'Question 3
If Range("AD13" ).Value = "Yes"  Then

    CheckBox15.Value = True
    CheckBox16.Value = False
ElseIf Range("AD13" ).Value = "No"  Then
    CheckBox15.Value = False
    CheckBox16.Value = True

End If

'Question 4


If Range("AH14" ).Value = "Yes"  Then

    CheckBox17.Value = True
    CheckBox18.Value = False
ElseIf Range("AH14" ).Value = "No"  Then
    CheckBox17.Value = False
    CheckBox18.Value = True

End If

'Question 4a
If Range("AD15" ).Value = "Monthly"  Then

    CheckBox19.Value = True
    CheckBox20.Value = False
    CheckBox21.Value = False
    CheckBox22.Value = False
    CheckBox23.Value = False

ElseIf Range("AD15" ).Value = "Quarterly"  Then

    CheckBox19.Value = False
    CheckBox20.Value = True
    CheckBox21.Value = False
    CheckBox22.Value = False
    CheckBox23.Value = False

ElseIf Range("AD15" ).Value = "Half-Yearly"  Then

    CheckBox19.Value = False
    CheckBox20.Value = False
    CheckBox21.Value = True
    CheckBox22.Value = False
    CheckBox23.Value = False

ElseIf Range("AD15" ).Value = "Yearly"  Then

    CheckBox19.Value = False
    CheckBox20.Value = False
    CheckBox21.Value = False
    CheckBox22.Value = True
    CheckBox23.Value = False

ElseIf Range("AD15" ).Value = "Others:"  Then

    CheckBox19.Value = False
    CheckBox20.Value = False
    CheckBox21.Value = False
    CheckBox22.Value = False
    CheckBox23.Value = True

End If
```

```
TextBox1003.Value = Range("AE15" ).Value

'Question 5
If Range("AE17" ).Value = "Yes"  Then

    CheckBox24.Value = True
    CheckBox25.Value = False
1 2
1 2
ElseIf Range("AF19" ).Value = "No"  Then
    CheckBox24.Value = False
    CheckBox25.Value = True

End If

'Question 6
If Range("AF19" ).Value = "Yes"  Then
    CheckBox26.Value = True
    CheckBox27.Value = False
    CheckBox28.Value = False
ElseIf Range("AF19" ).Value = "No"  Then
    CheckBox26.Value = False
    CheckBox27.Value = True
    CheckBox28.Value = False
ElseIf Range("AF19" ).Value = "N.A."  Then
    CheckBox26.Value = False
    CheckBox27.Value = False
    CheckBox28.Value = True
End If

'Question 7
If Range("AH20" ).Value = "Yes"  Then
    CheckBox29.Value = True
    CheckBox30.Value = False
ElseIf Range("AF19" ).Value = "No"  Then
    CheckBox29.Value = False
    CheckBox30.Value = True
End If
'Question 8

If Range("Y24" ).Value = ChrW(10003) Then
    Me.CheckBox31 = True
ElseIf Range("Y24" ).Value = ChrW(10007) Then
    Me.CheckBox31 = False
End If
If Range("Y25" ).Value = ChrW(10003) Then
    Me.CheckBox32 = True
ElseIf Range("Y25" ).Value = ChrW(10007) Then
    Me.CheckBox32 = False
End If

If Range("Y26" ).Value = ChrW(10003) Then
    Me.CheckBox33 = True
ElseIf Range("Y26" ).Value = ChrW(10007) Then
    Me.CheckBox33 = False
End If

If Range("Y27" ).Value = ChrW(10003) Then
    Me.CheckBox34 = True
ElseIf Range("Y27" ).Value = ChrW(10007) Then
    Me.CheckBox34 = False
End If

If Range("Y28" ).Value = ChrW(10003) Then
    Me.CheckBox35 = True
ElseIf Range("Y28" ).Value = ChrW(10007) Then
    Me.CheckBox35 = False
End If
1
1

TextBox1004.Value = Range("AA28" ).Value

'Question 9
If Range("AG29" ).Value = "Cyclical flushing type"  Then
```

```
            CheckBox36.Value = True
            CheckBox37.Value = False
            CheckBox38.Value = False
        ElseIf Range("AG29" ).Value = "Occupancy detector type"  Then

            CheckBox36.Value = False
            CheckBox37.Value = True
            CheckBox38.Value = False
        ElseIf Range("AG29" ).Value = "Motion sensor flush type"  Then

            CheckBox36.Value = False
            CheckBox37.Value = False
            CheckBox38.Value = True
        End If

        'Question 10
        If Range("AD30" ).Value = "Manually"  Then

            CheckBox39.Value = True
            CheckBox40.Value = False
            CheckBox41.Value = False
        ElseIf Range("AD30" ).Value = "Automatic closure"  Then

            CheckBox39.Value = False
            CheckBox40.Value = True
            CheckBox41.Value = False
        ElseIf Range("AD30" ).Value = "Sensor activated"  Then
        'Question 12
        If Range("AA34" ).Value = "Yes"  Then
            CheckBox44.Value = True
            CheckBox45.Value = False
        ElseIf Range("AA34" ).Value = "No"  Then
            CheckBox44.Value = False
            CheckBox45.Value = True

        End If

    i

    i
        'Question 13
        If Range("AF35" ).Value = "Yes"  Then
            CheckBox46.Value = True
            CheckBox47.Value = False
        ElseIf Range("AF35" ).Value = "No"  Then
            CheckBox46.Value = False
            CheckBox47.Value = True

        End If

        'Question 13a
        If Range("AE36" ).Value = "Monthly"  Then
            CheckBox48.Value = True
            CheckBox49.Value = False
            CheckBox50.Value = False
            CheckBox51.Value = False
            CheckBox52.Value = False


        ElseIf Range("AE36" ).Value = "Quarterly"  Then
            CheckBox48.Value = False
            CheckBox49.Value = True
            CheckBox50.Value = False
            CheckBox51.Value = False
            CheckBox52.Value = False


        ElseIf Range("AE36" ).Value = "Half-Yearly"  Then
            CheckBox48.Value = False
            CheckBox49.Value = False
            CheckBox50.Value = True
            CheckBox51.Value = False
            CheckBox52.Value = False


        ElseIf Range("AE36" ).Value = "Yearly"  Then
            CheckBox48.Value = False
            CheckBox49.Value = False
            CheckBox50.Value = False
            CheckBox51.Value = True
            CheckBox52.Value = False
```

```
ElseIf Range("AE36" ).Value = "Others:"  Then
    CheckBox48.Value = False
    CheckBox49.Value = False
    CheckBox50.Value = False
    CheckBox51.Value = False
    CheckBox52.Value = True

End If

TextBox1005.Value = Range("AF36" ).Value

'Question 14
If Range("AF38" ).Value = "Yes"  Then
    CheckBox53.Value = True
    CheckBox54.Value = False
ElseIf Range("AF38" ).Value = "No"  Then
    CheckBox53.Value = False
    CheckBox54.Value = True

End If

'Question 15
If Range("Z40" ).Value = "Water"  Then
    CheckBox55.Value = True
    CheckBox56.Value = False
    CheckBox57.Value = False
    CheckBox58.Value = False

ElseIf Range("Z40" ).Value = "Air"  Then
    CheckBox55.Value = False
    CheckBox56.Value = True
    CheckBox57.Value = False
    CheckBox58.Value = False

ElseIf Range("Z40" ).Value = "Other means excluding water"  Then
    CheckBox55.Value = False
    CheckBox56.Value = False
    CheckBox57.Value = True
    CheckBox58.Value = False

ElseIf Range("Z40" ).Value = "Combination of methods"  Then
    CheckBox55.Value = False
    CheckBox56.Value = False
    CheckBox57.Value = False
    CheckBox58.Value = True
End If

'Question 16
If Range("AH41" ).Value = "Yes"  Then
    CheckBox59.Value = True
    CheckBox60.Value = False
ElseIf Range("AH41" ).Value = "No"  Then
    CheckBox59.Value = False
    CheckBox60.Value = True
End If
'Question 17
If Range("AI42" ).Value = "Yes"  Then
    CheckBox61.Value = True
    CheckBox62.Value = False
ElseIf Range("AI42" ).Value = "No"  Then
    CheckBox61.Value = False
    CheckBox63.Value = True

End If

'Question 18
If Range("AJ43" ).Value = "Yes"  Then
    CheckBox63.Value = True
    CheckBox64.Value = False
ElseIf Range("AJ43" ).Value = "No"  Then
    CheckBox63.Value = False
    CheckBox64.Value = True

End If

'Question 19
If Range("AE46" ).Value = "Yes"  Then
```

```
1  2
        CheckBox65.Value = True
        CheckBox66.Value = False
    ElseIf Range("AE46" ).Value = "No"  Then
        CheckBox65.Value = False
        CheckBox66.Value = True

    End If

    'Question 20
    If Range("Z48" ).Value = "Monthly"  Then
        CheckBox67.Value = True
        CheckBox68.Value = False
        CheckBox69.Value = False
        CheckBox70.Value = False
        CheckBox71.Value = False


    ElseIf Range("Z48" ).Value = "Quarterly"  Then
        CheckBox67.Value = False
        CheckBox68.Value = True
        CheckBox69.Value = False
        CheckBox70.Value = False
        CheckBox71.Value = False


    ElseIf Range("Z48" ).Value = "Half-Yearly"  Then
        CheckBox67.Value = False
        CheckBox68.Value = False
        CheckBox69.Value = True
        CheckBox70.Value = False
        CheckBox71.Value = False

    ElseIf Range("Z48" ).Value = "Yearly"  Then
        CheckBox67.Value = False
        CheckBox68.Value = False
        CheckBox69.Value = False
        CheckBox70.Value = True
        CheckBox71.Value = False

    ElseIf Range("Z48" ).Value = "Others:"  Then
        CheckBox67.Value = False
        CheckBox68.Value = False
        CheckBox69.Value = False
        CheckBox70.Value = False
        CheckBox71.Value = True

    End If
    TextBox1006.Value = Range("AA48" ).Value

    'Question 21
    If Range("AD49" ).Value = "Manually"  Then
        CheckBox72.Value = True
        CheckBox73.Value = False
    ElseIf Range("AD49" ).Value = "Using automatic leak detectors"  Then
        CheckBox72.Value = False
        CheckBox73.Value = True
    End If

    'Question 21a
1

1
    If Range("AT4" ).Value = "Yes"  Then
        CheckBox74.Value = True
        CheckBox75.Value = False
    ElseIf Range("AT4" ).Value = "No"  Then
        CheckBox74.Value = False
        CheckBox75.Value = True
    End If

    'Question 22
    If Range("AP6" ).Value = "Yes"  Then
        CheckBox76.Value = True
        CheckBox77.Value = False
    ElseIf Range("AP6" ).Value = "No"  Then
        CheckBox76.Value = False
        CheckBox77.Value = True
    End If
```

```
'Question 23
If Range("AS11" ).Value = "Yes"  Then
    CheckBox78.Value = True
    CheckBox79.Value = False
ElseIf Range("AS11" ).Value = "No"  Then
    CheckBox78.Value = False
    CheckBox79.Value = True
End If

'Question 24
If Range("AV12" ).Value = "Yes"  Then
    CheckBox80.Value = True
    CheckBox81.Value = False
ElseIf Range("AV12" ).Value = "No"  Then
    CheckBox80.Value = False
    CheckBox81.Value = True
End If

'Question 25
If Range("AL17" ).Value = "Yes"  Then
    CheckBox82.Value = True
    CheckBox83.Value = False
ElseIf Range("AL17" ).Value = "No"  Then
    CheckBox82.Value = False
    CheckBox83.Value = True
End If
'Question 26
If Range("AO20" ).Value = "Yes"  Then
    CheckBox84.Value = True
    CheckBox85.Value = False
ElseIf Range("AO20" ).Value = "No"  Then
    CheckBox84.Value = False
    CheckBox85.Value = True
End If

'Question 27
If Range("AT22" ).Value = "Yes"  Then
    CheckBox86.Value = True
    CheckBox87.Value = False
ElseIf Range("AT22" ).Value = "No"  Then
    CheckBox86.Value = False
    CheckBox87.Value = True
End If

'Question 28
If Range("AN24" ).Value = "Yes"  Then
    CheckBox88.Value = True
    CheckBox89.Value = False
ElseIf Range("AN24" ).Value = "No"  Then
    CheckBox88.Value = False
    CheckBox89.Value = True
End If

'Question 29
If Range("AV25" ).Value = "Yes"  Then
    CheckBox90.Value = True
    CheckBox91.Value = False
ElseIf Range("AV25" ).Value = "No"  Then
    CheckBox90.Value = False
    CheckBox91.Value = True
End If

'Question 30
If Range("AO27" ).Value = "Yes"  Then
    CheckBox92.Value = True
    CheckBox93.Value = False
ElseIf Range("AO27" ).Value = "No"  Then
    CheckBox92.Value = False
    CheckBox93.Value = True
End If

'Question 31
If Range("AS28" ).Value = "Yes"  Then
    CheckBox94.Value = True
    CheckBox95.Value = False
ElseIf Range("AS28" ).Value = "No"  Then
    CheckBox94.Value = False
    CheckBox95.Value = True
End If
```

```
'Question 31a
If Range("AP29" ).Value = "Monthly"  Then
    CheckBox96.Value = True
    CheckBox97.Value = False
    CheckBox98.Value = False
    CheckBox99.Value = False
    CheckBox100.Value = False

ElseIf Range("AP29" ).Value = "Quarterly"  Then
    CheckBox96.Value = False
    CheckBox97.Value = True
    CheckBox98.Value = False
    CheckBox99.Value = False
    CheckBox100.Value = False

ElseIf Range("AP29" ).Value = "Half-Yearly"  Then
    CheckBox96.Value = False
    CheckBox97.Value = False
    CheckBox98.Value = True
    CheckBox99.Value = False
    CheckBox100.Value = False


ElseIf Range("AP29" ).Value = "Yearly"  Then
    CheckBox96.Value = False
    CheckBox97.Value = False
    CheckBox98.Value = False
    CheckBox99.Value = True
    CheckBox100.Value = False

ElseIf Range("AP29" ).Value = "Others:"  Then
    CheckBox96.Value = False
    CheckBox97.Value = False
    CheckBox98.Value = False
    CheckBox99.Value = False
    CheckBox100.Value = True

End If
'Question 33
If Range("AL33" ).Value = "Water use per unit product"  Then
    CheckBox103.Value = True
    CheckBox104.Value = False
ElseIf Range("AL33" ).Value = "Total water use per period"  Then
    CheckBox103.Value = False
    CheckBox104.Value = True
End If

'Question 34
If Range("AP37" ).Value = "Yes"  Then
    CheckBox105.Value = True
    CheckBox106.Value = False
ElseIf Range("AP37" ).Value = "No"  Then
    CheckBox105.Value = False
    CheckBox106.Value = True
End If

'Question 35
If Range("AT39" ).Value = "Yes"  Then
    CheckBox107.Value = True
    CheckBox108.Value = False
ElseIf Range("AT39" ).Value = "No"  Then
    CheckBox107.Value = False
    CheckBox108.Value = True
End If

'Question 36
If Range("AP41" ).Value = "Yes"  Then
    CheckBox109.Value = True
    CheckBox110.Value = False
ElseIf Range("AP41" ).Value = "No"  Then
```

```
        CheckBox109.Value = False
        CheckBox110.Value = True
    End If

    'Question 37
    If Range("AO43" ).Value = "Yes"  Then
        CheckBox111.Value = True
        CheckBox112.Value = False
    ElseIf Range("AO43" ).Value = "No"  Then
        CheckBox111.Value = False
        CheckBox112.Value = True
    End If

    'Question 38
    If Range("AQ45" ).Value = "Yes"  Then
        CheckBox113.Value = True
        CheckBox114.Value = False
    ElseIf Range("AQ45" ).Value = "No"  Then
        CheckBox113.Value = False
        CheckBox114.Value = True
    End If

    'Question 39
    If Range("AR47" ).Value = "Yes"  Then
        CheckBox115.Value = True
        CheckBox116.Value = False
    ElseIf Range("AR47" ).Value = "No"  Then
        CheckBox115.Value = False
        CheckBox116.Value = True
    End If

    'Question 40
    If Range("AV48" ).Value = "High"  Then
        CheckBox117.Value = True
        CheckBox118.Value = False
        CheckBox119.Value = False
        CheckBox120.Value = False

    ElseIf Range("AV48" ).Value = "Average"  Then
        CheckBox117.Value = False
        CheckBox118.Value = True
        CheckBox119.Value = False
        CheckBox120.Value = False

    ElseIf Range("AV48" ).Value = "Low"  Then
        CheckBox117.Value = False
        CheckBox118.Value = False
        CheckBox119.Value = True
        CheckBox120.Value = False

    ElseIf Range("AV48" ).Value = "N.A."  Then
        CheckBox117.Value = False
        CheckBox118.Value = False
        CheckBox119.Value = False
        CheckBox120.Value = True

    End If

End Sub

Sub UserForm111_Click()

    count_of_1 = 0
    count_of_2 = 0
    count_of_3 = 0
    count_of_4 = 0
    count_of_5 = 0

    'Question 1
    If CheckBox1.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox2.Value = True Then count_of_2 = count_of_2 + 1

    'Question 1a
    If CheckBox3.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox4.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox5.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox6.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox7.Value = True Then count_of_2 = count_of_2 + 1
```

```
'Question 2
If CheckBox8.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox9.Value = True Then count_of_5 = count_of_5 + 1

'Question 2a
If CheckBox10.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox11.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox12.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox13.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox14.Value = True Then count_of_2 = count_of_2 + 1

'Question 3
If CheckBox15.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox16.Value = True Then count_of_5 = count_of_5 + 1

'Question 4
If CheckBox17.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox18.Value = True Then count_of_5 = count_of_5 + 1

'Question 4a
If CheckBox19.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox20.Value = True Then count_of_2 = count_of_2 + 1
If CheckBox21.Value = True Then count_of_3 = count_of_3 + 1
If CheckBox22.Value = True Then count_of_4 = count_of_4 + 1
If CheckBox23.Value = True Then count_of_5 = count_of_5 + 1

'Question 5
If CheckBox24.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox25.Value = True Then count_of_5 = count_of_5 + 1

'Question 6
If CheckBox26.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox27.Value = True Then count_of_5 = count_of_5 + 1
If CheckBox28.Value = True Then count_of_1 = count_of_1 + 1

'Question 7
If CheckBox29.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox30.Value = True Then count_of_5 = count_of_5 + 1


'Question 8
If CheckBox31.Value = True Then count_of_3 = count_of_3 + 1
If CheckBox32.Value = True Then count_of_3 = count_of_3 + 1
If CheckBox33.Value = True Then count_of_3 = count_of_3 + 1
If CheckBox34.Value = True Then count_of_3 = count_of_3 + 1
If CheckBox35.Value = True Then count_of_3 = count_of_3 + 1

'Question 9
If CheckBox36.Value = True Then count_of_4 = count_of_4 + 1
If CheckBox37.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox38.Value = True Then count_of_1 = count_of_1 + 1

'Question 10
If CheckBox39.Value = True Then count_of_4 = count_of_4 + 1
If CheckBox40.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox41.Value = True Then count_of_1 = count_of_1 + 1

'Question 11
If CheckBox42.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox43.Value = True Then count_of_5 = count_of_5 + 1

'Question 12
If CheckBox44.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox45.Value = True Then count_of_5 = count_of_5 + 1

'Question 13
If CheckBox46.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox47.Value = True Then count_of_5 = count_of_5 + 1
'Question 13a
If CheckBox48.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox49.Value = True Then count_of_2 = count_of_2 + 1
If CheckBox50.Value = True Then count_of_3 = count_of_3 + 1
If CheckBox51.Value = True Then count_of_4 = count_of_4 + 1
If CheckBox52.Value = True Then count_of_5 = count_of_5 + 1

'Question 14
If CheckBox53.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox54.Value = True Then count_of_5 = count_of_5 + 1
```

```
'Question 15
If CheckBox55.Value = True Then count_of_4 = count_of_4 + 1
If CheckBox56.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox57.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox58.Value = True Then count_of_2 = count_of_2 + 1

'Question 16
If CheckBox59.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox60.Value = True Then count_of_5 = count_of_5 + 1

'Question 17
If CheckBox61.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox62.Value = True Then count_of_5 = count_of_5 + 1

'Question 18
If CheckBox63.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox64.Value = True Then count_of_5 = count_of_5 + 1

'Question 19

If CheckBox65.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox66.Value = True Then count_of_5 = count_of_5 + 1

'Question 20
If CheckBox67.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox68.Value = True Then count_of_2 = count_of_2 + 1
If CheckBox69.Value = True Then count_of_3 = count_of_3 + 1
If CheckBox70.Value = True Then count_of_4 = count_of_4 + 1
If CheckBox71.Value = True Then count_of_5 = count_of_5 + 1

'Question 21
If CheckBox72.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox73.Value = True Then count_of_5 = count_of_5 + 1

'Question 21a
If CheckBox74.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox75.Value = True Then count_of_5 = count_of_5 + 1

'Question 22
If CheckBox76.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox77.Value = True Then count_of_5 = count_of_5 + 1

'Question 23
If CheckBox78.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox79.Value = True Then count_of_5 = count_of_5 + 1

'Question 24
If CheckBox80.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox81.Value = True Then count_of_5 = count_of_5 + 1

'Question 25
If CheckBox82.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox83.Value = True Then count_of_5 = count_of_5 + 1

'Question 26
If CheckBox84.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox85.Value = True Then count_of_5 = count_of_5 + 1

'Question 27
If CheckBox86.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox87.Value = True Then count_of_5 = count_of_5 + 1

'Question 28
If CheckBox88.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox89.Value = True Then count_of_5 = count_of_5 + 1

'Question 29
If CheckBox90.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox91.Value = True Then count_of_5 = count_of_5 + 1

'Question 30
If CheckBox92.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox93.Value = True Then count_of_5 = count_of_5 + 1

'Question 31
If CheckBox94.Value = True Then count_of_1 = count_of_1 + 1
If CheckBox95.Value = True Then count_of_5 = count_of_5 + 1

'Question 31a
If CheckBox96.Value = True Then count_of_1 = count_of_1 + 1
```

```
    If CheckBox97.Value = True Then count_of_2 = count_of_2 + 1
    If CheckBox98.Value = True Then count_of_3 = count_of_3 + 1
    If CheckBox99.Value = True Then count_of_4 = count_of_4 + 1
    If CheckBox100.Value = True Then count_of_5 = count_of_5 + 1

    'Question 32
    If CheckBox101.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox102.Value = True Then count_of_5 = count_of_5 + 1

    'Question 33
    If CheckBox103.Value = True Then count_of_2 = count_of_2 + 1
    If CheckBox104.Value = True Then count_of_1 = count_of_1 + 1

    'Question 34
    If CheckBox105.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox106.Value = True Then count_of_5 = count_of_5 + 1

    'Question 35
    If CheckBox107.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox108.Value = True Then count_of_5 = count_of_5 + 1

    'Question 36
    If CheckBox109.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox110.Value = True Then count_of_5 = count_of_5 + 1

    'Question 37
    If CheckBox111.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox112.Value = True Then count_of_5 = count_of_5 + 1

    'Question 38
    If CheckBox113.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox114.Value = True Then count_of_5 = count_of_5 + 1

    'Question 39
    If CheckBox115.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox116.Value = True Then count_of_5 = count_of_5 + 1

    'Question 40
    If CheckBox117.Value = True Then count_of_1 = count_of_1 + 1
    If CheckBox118.Value = True Then count_of_2 = count_of_2 + 1
    If CheckBox119.Value = True Then count_of_4 = count_of_4 + 1
    If CheckBox120.Value = True Then count_of_5 = count_of_5 + 1

    Dim i As Control
    Dim k As Long
    For Each i In Frm_Process_Assessment.Controls
      If TypeOf i Is MSForms.CheckBox Then
        If Frm_Process_Assessment.Controls(i.Name).Value = True Then
          k = k + 1
        End If
      End If
    Next

    Dim Number_of_questions As Integer
    Dim average_value As Long
    Dim water_savings_potential As Long

    On Error GoTo Clear_Entry
    Number_of_questions = k
    average_value = (((100 * count_of_1) + (50 * count_of_2) + (20 * count_of_3) + (10 *
     count_of_4) + (0 * count_of_5)) / Number_of_questions)
    If average_value <> 0 Then average_value = Format(average_value, "#.##" )
    water_savings_potential = (100 - average_value)

    Label1.Caption = "From the performance assessment, you are currently saving "  &
    average_value & "% of the conservable water on your site."
    Label10.Caption = "This indicates that the site still has the potential for circa "
     & water_savings_potential & "% water savings."
```

```
    Clear_Entry:
    If Number_of_questions = 0 Then
      Label1.Caption = ""
      Label10.Caption = ""
      Label11.Caption = ""
      Me.Pass_Assessment_Ouput_Into_Results_Sheet.Enabled = False
    Else
      Label1.Caption = "From the performance assessment, you are currently saving " &
      average_value & "% of the conservable water on your site."
      Label10.Caption = "This indicates that the site still has the potential for
      circa "  & water_savings_potential & "% water savings."
      Label11.Caption = "Click on this button to transfer this assessment output to
      the benchmarking results sheet for printing:"
      Me.Pass_Assessment_Ouput_Into_Results_Sheet.Enabled = True
    End If

    Exit Sub
End Sub

Sub UserForm111_Initialize()

    Me.ScrollBars = fmScrollBarsBoth
    Me.ScrollHeight = Me.InsideHeight * 7

End Sub
```

9.1.8 frm_FieldSpecify1

frm_FieldSpecify1 VBAProject

```
Option Explicit

Public Site01_Row As Long
Public Site02_Row As Long

Public PeriodA_Row As Long
Public PeriodB_Row As Long

Private Sub cmdEndPeriod_Click()
    txtEndPeriod.Text = ActiveCell.Value
    txtEndPeriod.Tag = ActiveCell.Column
    PeriodB_Row = ActiveCell.Row
End Sub

Private Sub cmdOK_Click()

    Dim n As Long
    Dim m As Long

    Dim j As Long
    Dim k As Long

    Dim Period_Data() As String
    Dim Period_Date() As String

    Dim Destination_Start_Title_Row As Long
    Dim Destination_Start_Title_Col As Long

    Dim Destination_Row_Cnt As Long
    Dim SiteNumber_Source As String

    On Error GoTo ErrHandler:

    'Do error checking first...
    If CheckValidPeriod(txtStartPeriod) = False Or _
        CheckValidPeriod(txtEndPeriod) = False Then

      MsgBox "The period you've specified seems to be invalid..."  & vbCrLf & _
      "Please check that it follows any of the following formats: "  & vbCrLf & _
      "19##, 19##-##, 20##, 20##-##, ... OR Jan,Feb,...Dec OR "  & vbCrLf & _
      "January,February,...December OR "  & vbCrLf & _
      "January/February, March/April, ... November/December OR"  & vbCrLf & _
      "Jan/Feb, Mar/Apr, ... Nov/Dec OR"  & vbCrLf & _
      "January-February, March-April, ... November-December OR"  & vbCrLf & _
      "Jan-Feb, Mar-Apr, ... Nov-Dec OR" , vbOKOnly + vbInformation, "Warning!"

      Exit Sub
    End If
```

```
If Val(txtStartPeriod.Tag) > Val(txtEndPeriod.Tag) Then
  MsgBox "The start period appears to be greater than the end period."  & vbCrLf &
  _
  "Please check this and try again" , vbOKOnly + vbInformation, "Warning"
  txtStartPeriod.Value = ""
  txtEndPeriod.Value = ""
  Exit Sub
End If

If Val(Site01_Row) > Val(Site02_Row) Then
  MsgBox "The start site appears to be greater than the last site."  & vbCrLf & _
1 2

1 2
  "Please check this and try again" , vbOKOnly + vbInformation, "Warning"
  txtSiteStart.Value = ""
  txtSiteLast.Value = ""
  Exit Sub
End If

If Val(PeriodB_Row) <> Val(PeriodA_Row) Then
  MsgBox "The start period and end period were not on the same row"  & vbCrLf & _
  "Please check this and try again" , vbOKOnly + vbInformation, "Warning"
  txtStartPeriod.Value = ""
  txtEndPeriod.Value = ""
  Exit Sub
End If

If Val(PeriodA_Row) = Site01_Row Or _
    Val(PeriodB_Row) = Site02_Row Then
  MsgBox "The start site appears to be incorrect (i.e. lines up with the period
  ROW)"  & vbCrLf & _
  "Please check this and try again" , vbOKOnly + vbInformation, "Warning"
  txtSiteStart.Value = ""
  txtSiteLast.Value = ""
  Exit Sub
End If

If Val(txtSiteStart.Tag) <> 1 Or _
    Val(txtSiteLast.Tag) <> 1 Then
  MsgBox "The first and/or last site selection appears to be outside the valid
  column"  & vbCrLf & _
  "Please check and make sure the selection made is under column A only!" ,
  vbOKOnly + vbInformation, "Warning"
  txtSiteStart.Value = ""
  txtSiteLast.Value = ""
  Exit Sub
End If

If Val(PeriodA_Row) <> 2 Or _
    Val(PeriodB_Row) <> 2 Then
  MsgBox "The first and/or last period selection appears to be outside the valid
  row"  & vbCrLf & _
  "Please check and make sure the selection made is under row 2 only!" , vbOKOnly +
   vbInformation, "Warning"
  txtStartPeriod.Value = ""
  txtEndPeriod.Value = ""
  Exit Sub
End If
  Application.ScreenUpdating = False
  Application.Interactive = False

  'Copy the Data from 'Data Entry Sheet' to 'Data input and Validation'

  Destination_Start_Title_Row = 11
  Destination_Start_Title_Col = 1

  'txtStartPeriod.Tag 'Column Number for the Start of Period
  'txtEndPeriod.Tag 'Column Number for the End of Period

  Destination_Row_Cnt = Destination_Start_Title_Row

  ReDim Period_Data(txtEndPeriod.Tag - txtStartPeriod.Tag)
1
```

```
ReDim Period_Date(txtEndPeriod.Tag - txtStartPeriod.Tag)

For n = Site01_Row To Site02_Row
    'Make sure we start at 'Data Entry Sheet'
    Sheets("Data Entry Sheet" ).Select

    If IsEmpty(Cells(n, 1).Value) = True Then Exit For

    'Read Site Number
    SiteNumber_Source = Cells(n, Val(txtSiteStart.Tag)).Value

    'Read First to Last Date Data
    For m = 0 To (txtEndPeriod.Tag - txtStartPeriod.Tag)
        Period_Data(m) = CStr(Cells(n, Val(txtStartPeriod.Tag) + m).Value)
        Period_Date(m) = CStr(Cells(2, Val(txtStartPeriod.Tag) + m).Value)
    Next m

    'Jump over to 'Data input and Validation'
    Sheets("Data input and Validation" ).Visible = True
    Sheets("Data input and Validation" ).Select

    'Clear entries (if existing)
    Dim row_1 As Long
    Dim col_1 As Long

    If n = Site01_Row Then                              'clear entries on first loop
        'Data and Site
        For row_1 = 12 To Rows.Count
            If IsEmpty(Cells(row_1, 1).Value) = True Then Exit For
            For col_1 = 1 To 21 'Columns.Count
                Cells(row_1, col_1).Value = ""  'clear entry on that cell
            Next col_1
        Next row_1

        'Year/Period
        For col_1 = 2 To 21                             'Columns.Count
            Cells(11, col_1).Value = ""                 'clear entry on that cell
        Next col_1
    End If

    Destination_Row_Cnt = Destination_Row_Cnt + 1
    Cells(Destination_Row_Cnt, 1).Value = SiteNumber_Source

    'Update the Dates/Data...
    k = 0
    For j = 2 To 2 + (txtEndPeriod.Tag - txtStartPeriod.Tag)
        Cells(Destination_Start_Title_Row, j).Value = Period_Date(k)
        'The Date on the title
        If Len(Period_Data(k)) = 0 Or Period_Data(k) = "-"  Then
            Cells(Destination_Row_Cnt, j).Value = ""
            'Period Data
        Else
            Cells(Destination_Row_Cnt, j).Value = Format(Period_Data(k), "0.0000" )
            'Period Data
        End If
        'Cells(Destination_Row_Cnt, j).Select
        'Selection.NumberFormat = "0.0000"
        k = k + 1
    Next j
Next n



Application.ScreenUpdating = True
Application.Interactive = True
Me.Hide

Exit Sub

ErrHandler:
Application.ScreenUpdating = True
Application.Interactive = True
txtStartPeriod.Value = ""
txtEndPeriod.Value = ""
txtSiteStart.Value = ""
txtSiteLast.Value = ""
```

```
    MsgBox "You have either made an invalid selection, or not populated the four
    textboxes, "  & vbCrLf & _
    "or not provided valid descriptions for the period. "  & vbCrLf & _
    "Please follow the direction on the Specify Field form "  & vbCrLf & _
    "and ensure that your period descriptions are in the following formats: "  & vbCrLf
    & _
    "19##, 19##-##, 20##, 20##-##, ... OR Jan,Feb,...Dec OR "  & vbCrLf & _
    "January,February,...December OR "  & vbCrLf & _
    "January/February, March/April, ... November/December OR"  & vbCrLf & _
    "Jan/Feb, Mar/Apr, ... Nov/Dec OR"  & vbCrLf & _
    "January-February, March-April, ... November-December OR"  & vbCrLf & _
    "Jan-Feb, Mar-Apr, ... Nov-Dec OR" , vbOKOnly + vbInformation, "Warning!"

End Sub

Private Sub cmdSelSiteLast_Click()

    txtSiteLast.Text = ActiveCell.Value
    txtSiteLast.Tag = ActiveCell.Column
    Site02_Row = ActiveCell.Row
End Sub

Private Sub cmdSelSiteStart_Click()

    txtSiteStart.Text = ActiveCell.Value
    txtSiteStart.Tag = ActiveCell.Column
    Site01_Row = ActiveCell.Row

End Sub

Private Sub cmdStrtPeriod_Click()

    txtStartPeriod.Text = ActiveCell.Value
    txtStartPeriod.Tag = ActiveCell.Column
    PeriodA_Row = ActiveCell.Row
End Sub

Private Sub UserForm_Activate()

    Sheets("Data Entry Sheet" ).Select
    'Start with clean / empty data on text boxes...

    txtStartPeriod.Text = ""
    txtEndPeriod.Text = ""
    txtSiteStart.Text = ""
1
1
    txtSiteLast.Text = ""

    'Lock from user
    txtStartPeriod.Locked = True
    txtEndPeriod.Locked = True
    txtSiteStart.Locked = True
    txtSiteLast.Locked = True

End Sub
```

9.1.9 *frm_Config_Charts*

frm_Config_Charts VBAProject

```
Option Explicit
Public rXf As New Collection 'x-Axis values (Chart 1), Series (Other Charts...)
Public rSf As New Collection 'Series Collection Names (Chart 1), x-Axis values (Other
Charts...)

Private Sub Benchmarking_Results_Show_Click()
    Unload Me
    Worksheets("Benchmarking Results" ).Activate
    Range("a1" ).Select
End Sub
```

```
Private Sub Benchmarking_Specifics_Click()
    Unload Me
    frm_Benchmarking_Specifics.Show
End Sub

Private Sub Benchmarking_Start_Form_Click()
    Unload Me
    frm_Benchmarking_Start_Form.Show
End Sub

Private Sub ComboBox1_Click()
    ComboBox2.Enabled = True
    ComboBox2.Text = ""
End Sub

Private Sub ComboBox1_Enter()
    Dim n As Long

    ComboBox1.Clear
    For n = 1 To rXf.Count
        ComboBox1.AddItem rXf(n)
    Next

End Sub

Private Sub ComboBox2_Click()
    ComboBox3.Enabled = True
End Sub

Private Sub ComboBox2_Enter()
    Dim n As Long

    ComboBox2.Clear
    For n = ComboBox1.ListIndex + 1 To rXf.Count
        ComboBox2.AddItem rXf(n)
    Next
End Sub

Private Sub ComboBox3_Enter()
    Dim n As Long

    ComboBox3.Clear
    For n = 1 To rSf.Count
        ComboBox3.AddItem rSf(n)
    Next

End Sub

Private Sub CommandButton1_Click()

    If ComboBox1.Text = "" Or _
       ComboBox2.Text = "" Or _
       ComboBox3.Text = "" Then Exit Sub

    Sheets("Benchmarking results").Select

    col_Index = ComboBox1.ListIndex + 1
    co2_Index = ComboBox1.ListIndex + 1 + ComboBox2.ListIndex

    If co2_Index - col_Index > 20 Then
        If MsgBox("It is recommended that you do not select more than 20 sites at
        once..." & vbCrLf & _
                "Do you want to reduce the number of sites?", vbInformation + vbYesNo
        , "Warning") = vbYes Then
            Exit Sub
        End If
    End If

    Update_Chart4 col_Index, co2_Index
    Update_Chart5 ComboBox1.ListIndex + 1, ComboBox1.ListIndex + 1 + ComboBox2.ListIndex
    , ComboBox3.ListIndex + 1

    Me.Hide

End Sub

Private Sub CommandButton2_Click()

    If IsEmpty(Worksheets("Data input and Validation").Range("B11:C12").Value) = False
    _
        And IsEmpty(Worksheets("Data input and Validation").Range("A12").Value) =
        False Then
        Update_Chart4 1, 2
        Update_Chart5 1, 2, 2
```

```
        Else
            Update_Chart4 1, 1
            Update_Chart5 1, 1, 1
        End If
        Me.Hide
    End Sub

    Private Sub Contact_Information_Click()
        Unload Me
        frm_Contact_Information.Show
    End Sub

    Private Sub Data_InputAndValidation_Click()
        Unload Me
        Worksheets("Data input and Validation" ).Activate
        Range("a1" ).Select
    End Sub

    Private Sub Home_Page_Click()
        Worksheets("Home page" ).Activate
        Range("a1" ).Select
        Unload Me
    End Sub

    Private Sub UserForm_Activate()
        Dim n As Long
        Dim kTf As Data_Table       'Series Values (in an array/i.e. range)

        'clear the rxF and rSF first
        For n = rXf.Count To 1 Step -1
            rXf.Remove (n)
        Next n

        'For n = 1 To rXf.Count
        'rXf.Remove (1)
        'Next n

        For n = rSf.Count To 1 Step -1
            rSf.Remove (n)
        Next n

        GetTable "Data input and Validation" , 12, 2, rXf, rSf, kTf

        ComboBox1.Clear: ComboBox1.Text = ""
        ComboBox2.Clear: ComboBox2.Text = "" : ComboBox2.Enabled = False
        ComboBox3.Clear: ComboBox3.Text = "" : ComboBox3.Enabled = False

        Sheets("Benchmarking results" ).Select

    End Sub

    Private Sub UserForm_Terminate()

        If IsEmpty(Worksheets("Data input and Validation" ).Range("B11:C12" ).Value) = False
          _
                And IsEmpty(Worksheets("Data input and Validation" ).Range("A12" ).Value) =
            False Then
            Update_Chart4 1, 2
            Update_Chart5 1, 2, 2
        Else
            Update_Chart4 1, 1
            Update_Chart5 1, 1, 1
        End If

    End Sub
```

9.1.10 frm_DataSampleFormat1

frm_DataSampleFormat1 VBAProject

```
Option Explicit

Private Sub Show_Data_Entry_Sheet_Click()

    Dim ActiveView As String

    Application.ScreenUpdating = False
    Application.Interactive = False
    Worksheets("Home page" ).Visible = True

    ActiveView = ActiveSheet.Name

    Worksheets("Data Input and Validation" ).Visible = xlVeryHidden

    FORMAT_SELECTED = 1
    Unload Me
    MsgBox "Thanks"  & vbCrLf & "Now click on the Input Data tab" , vbOKOnly +
    vbInformation, "Information"

    frm_Benchmarking_Specifics.Show

    Application.ScreenUpdating = True
    Application.Interactive = True
End Sub

Private Sub Show_DataSampleFormat2_Click()
    Unload Me
    frm_DataSampleFormat2.Show
End Sub

Private Sub UserForm_Activate()

    Dim ActiveView As String

    Application.ScreenUpdating = False
    Application.Interactive = False

    Sheets("Home Page" ).Select

    ActiveView = ActiveSheet.Name
    Sheets("Data Input and Validation" ).Visible = xlVeryHidden

    Application.ScreenUpdating = True
    Application.Interactive = True


End Sub

Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)
    If CloseMode = 0 Then
        Cancel = True
        MsgBox "X is disabled on this form!"  & vbCrLf & "Please click on any other
        tab." , vbCritical
    End If
End Sub
```

9.1.11 frm_Tool_Operation

frm_Tool_Operation VBAProject

```
Option Explicit

Private Sub Auto_Open_Click()
    Sheets("Home page" ).Visible = True
    Sheets("Home page" ).Select
    Range("a1" ).Select
    Unload Me
End Sub
```

```
Private Sub CommandButton1_Click()
    Application.DisplayAlerts = True
    ActiveWorkbook.Close
End Sub

Private Sub UserForm_Activate()
    Application.DisplayAlerts = True
End Sub
Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)
    If CloseMode = 0 Then
        Cancel = True
        MsgBox "X is disabled on this form!"  & vbCrLf & "Please click on any other
        tab." , vbCritical
    End If
End Sub
```

9.1.12 frm_Benchmarking_Start_Form

frm_Benchmarking_Start_Form VBAProject

```
Private Sub Benchmarking_Results_Click()
    SELECTION_ORDER = 4
    If SELECTION_ORDER = 1 Or SELECTION_ORDER = 2 Or SELECTION_ORDER = 3 Then
    Else
        MsgBox "Each Benchmarking step follows an order. Please start from the Contact
        Information; then click Next on the Contact Information form, this will take you
        to the Benchmarking Specifics form. Accordingly, click on the form's Next tab to
        access the Data Input and Validation sheet. Further steps to the Benchmarking
        Results sheet are contain on this sheet ..." , vbCritical + vbOKOnly, "Err Msg"
    End If

    If SELECTION_ORDER = 1 Or SELECTION_ORDER = 2 Or SELECTION_ORDER = 3 Then
        Unload Me
        Worksheets("Benchmarking Results" ).Activate
        Range("a1" ).Select
    End If
End Sub

Private Sub Benchmarking_Specifics_Click()
    SELECTION_ORDER = 2
    If SELECTION_ORDER = 1 Then
    Else
        MsgBox "Each Benchmarking step follows an order. Please start from the Contact
        Information, then click Next on the Contact Information form; this will take you
        to the Benchmarking Specifics form ..." , vbCritical + vbOKOnly, "Err Msg"
    End If
    If SELECTION_ORDER = 1 Then
        Unload Me
        frm_Benchmarking_Specifics.Show
    End If
End Sub

Private Sub Contact_Information_Click()

    SELECTION_ORDER = 1
    Unload Me
    frm_Contact_Information.Show

End Sub

Private Sub Data_InputAndValidation_Click()
    SELECTION_ORDER = 3
    If SELECTION_ORDER = 1 Or SELECTION_ORDER = 2 Then
    Else
        MsgBox "Each Benchmarking step follows an order. Please start from the Contact
        Information; then click Next on the Contact Information form, this will take you
        to the Benchmarking Specifics form. Lastly, click on the Next tab to access the
        Data Input and Validation sheet ..." , vbCritical + vbOKOnly, "Err Msg"
    End If

    If SELECTION_ORDER = 1 Or SELECTION_ORDER = 2 Then
        Unload Me
        Worksheets("Data input and Validation" ).Activate
        Range("a1" ).Select
    End If
End Sub
```

9.1.13 frm_Application_Information

frm_Application_Information VBAProject

```
Private Sub cmdCancel_Click()
  Worksheets("Home page" ).Activate
  Range("a1" ).Select
  Unload Me
End Sub

Private Sub cmdNext_Worksheet_Click()
  Unload Me
  frm_Benchmarking_Start_Form.Show

End Sub

Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

  If CloseMode = 0 Then
    Cancel = True
    MsgBox "The X is disabled, please use a button on the form." , vbCritical
  End If

End Sub
```

9.1.14 frm_Benchmarking_Specifics

frm_Benchmarking_Specifics VBAProject

```
Private Sub Benchmarking_Results_Click()
  SELECTION_ORDER = 4
  If SELECTION_ORDER = 1 Or SELECTION_ORDER = 2 Or SELECTION_ORDER = 3 Then
  Else
    MsgBox "Each Benchmarking step follows and order. Please click on the Input data
    tab ..." , vbCritical + vbOKOnly, "Err Msg"
  End If

  If SELECTION_ORDER = 1 Or SELECTION_ORDER = 2 Or SELECTION_ORDER = 3 Then
    Unload Me
    Worksheets("Benchmarking Results" ).Activate
    Range("a1" ).Select
  End If
End Sub
Private Sub Benchmarking_Specifics_Click()
  Unload Me
  frm_Benchmarking_Specifics.Show
End Sub

Private Sub Benchmarking_Start_Form_Click()
  Unload Me
  frm_Benchmarking_Start_Form.Show
End Sub


Private Sub cmd_Data_Input_Sheet_Click()
  Unload Me
  Worksheets("Data input and Validation" ).Activate
  Range("a1" ).Select
End Sub

Private Sub ComboBox13_Click()
  'stop here...
  KPI = ComboBox13.Text

End Sub

Private Sub ComboBox13_Enter()

  ComboBox13.Clear

  If INDUSTRIAL_SECTOR = "Manufacturing"  Then
    ComboBox13.AddItem "Water Use per Unit Product (Relative)"
    ComboBox13.AddItem "Water Use (Absolute)"
  Else
    ComboBox13.AddItem "Water Use per Unit Product (Relative)"
    ComboBox13.AddItem "Water Use (Absolute)"
  End If

End Sub
```

```
Private Sub ComboBox14_Click()

   BENCHMARK_UNIT = ComboBox14.Text
   BENCHMARK_INDEX = ComboBox14.ListIndex + 1

   If ComboBox13.Text <> "Water Use (Absolute)"  Then
      BENCHMARK_UL = BenchMark_UL_List(BENCHMARK_INDEX)
      BENCHMARK_LL = BenchMark_LL_List(BENCHMARK_INDEX)

      'Else
   End If
End Sub

Private Sub ComboBox14_Enter()

   Dim BENCHMARK_UNIT_COL As New Collection

   If ComboBox13.Text = "Water Use per Unit Product (Relative)"  Then

      GetBenchMark_Data "Database" , 1, 2, 6, 3, 4, 5, BENCHMARK_UNIT_COL
      ComboBox14.Clear

      For n = 1 To BENCHMARK_UNIT_COL.Count
         ComboBox14.AddItem BENCHMARK_UNIT_COL(n)
      Next n
   End If

   If ComboBox13.Text = "Water Use (Absolute)"  Then
      ComboBox14.Clear
      ComboBox14.AddItem "Litres"
      ComboBox14.AddItem "m³"

   End If
End Sub

Private Sub ComboBox15_Click()
   DIV_SEL = ComboBox15.Text
   ComboBox16.Clear: ComboBox16.Text = "Select"
   ComboBox17.Clear: ComboBox17.Text = "Select"
   ComboBox13.Clear: ComboBox13.Text = "Select"
   ComboBox14.Clear: ComboBox14.Text = "Select"
End Sub

Private Sub ComboBox15_Enter()
   Dim myCol As New Collection
   Dim n As Long

   Call Label33_Click

   GetUniqueEntries "Database" , 1, 2, myCol, "thermo"

   ComboBox15.Clear

   For n = 1 To myCol.Count
      ComboBox15.AddItem myCol.Item(n)
   Next n
End Sub

Private Sub ComboBox16_Click()
   SEG_SEL = ComboBox16.Text

   ComboBox17.Clear: ComboBox17.Text = "Select"
   ComboBox13.Clear: ComboBox13.Text = "Select"
   ComboBox14.Clear: ComboBox14.Text = "Select"

End Sub

Private Sub ComboBox16_Enter()
   Dim myCol As New Collection

   Dim n As Long

   Call Label17_Click

   GetUniqueEntries "Database" , 6, 2, myCol, , 1, 2

   ComboBox18.Clear

   For n = 1 To myCol.Count
      ComboBox18.AddItem myCol.Item(n)
   Next n

End Sub
```

```
Private Sub ComboBox5_Click()
    DIV_SEL = ComboBox5.Text
    ComboBox6.Clear: ComboBox6.Text = "Select"
    ComboBox18.Clear: ComboBox18.Text = "Select"
    ComboBox13.Clear: ComboBox13.Text = "Select"
    ComboBox14.Clear: ComboBox14.Text = "Select"
End Sub

Private Sub ComboBox5_Enter()
    Dim myCol As New Collection
    Dim n As Long

    Call Label17_Click

    GetUniqueEntries "Database" , 1, 2, myCol

    ComboBox5.Clear

    For n = 1 To myCol.Count
        ComboBox5.AddItem myCol.Item(n)
    Next n
End Sub

Private Sub ComboBox6_Click()
    SEG_SEL = ComboBox6.Text
    ComboBox18.Clear: ComboBox18.Text = "Select"
    ComboBox13.Clear: ComboBox13.Text = "Select"
    ComboBox14.Clear: ComboBox14.Text = "Select"

End Sub

Private Sub ComboBox6_Enter()
    Dim myCol As New Collection
    Dim n As Long

    Call Label17_Click

    GetUniqueEntries "Database" , 2, 2, myCol, , 1

    ComboBox6.Clear

    For n = 1 To myCol.Count
        ComboBox6.AddItem myCol.Item(n)
    Next n
End Sub

Private Sub CommandButton1_Click()
    frm_DataSampleFormat1.Show
End Sub

Private Sub Contact_Information_Click()
    Unload Me
    frm_Contact_Information.Show
End Sub

Private Sub Data_InputAndValidation_Click()
    SELECTION_ORDER = 3
    If SELECTION_ORDER = 1 Or SELECTION_ORDER = 2 Then
    Else
        MsgBox "Each Benchmarking step follows an order. Please click on the Input data
        tab ..." , vbCritical + vbOKOnly, "Err Msg"
    End If

    If SELECTION_ORDER = 1 Or SELECTION_ORDER = 2 Then
        Unload Me
        Worksheets("Data input and Validation" ).Activate
        Range("a1" ).Select
    End If
End Sub

Private Sub Frame3_MouseMove(ByVal Button As Integer, ByVal Shift As Integer, ByVal x
As Single, ByVal Y As Single)
    Label17.ForeColor = vbBlue
    Label33.ForeColor = vbBlue
End Sub

Private Sub Home_Page_Click()

    Worksheets("Data Input and Validation" ).Visible = xlVeryHidden
    Worksheets("Home page" ).Activate
    Range("a1" ).Select
    Unload Me
End Sub
Private Sub Input_Data_Click()
```

```
If ComboBox14.Text = "Select"  Or _
    ComboBox13.Text = "Select"  Then

  MsgBox "Some required entries are missing...please check!" , vbOKOnly +
  vbExclamation, "Warning"

  Exit Sub
End If

'Unload Me

If FORMAT_SELECTED = 1 Or FORMAT_SELECTED = 2 Then
Else
  Worksheets("Data Input and Validation" ).Visible = xlVeryHidden
  MsgBox "You have not selected a suitable data format yet..." , vbCritical +
  vbOKOnly, "Err Msg"
  'frm_Benchmarking_Specifics.Show vbModal
  Exit Sub
End If

If FORMAT_SELECTED = 1 Then

  Worksheets("Data Input and Validation" ).Visible = xlVeryHidden
  Sheets("Data Entry Sheet." ).Visible = xlVeryHidden
  Sheets("Data Entry Sheet" ).Visible = True
  Worksheets("Data Entry Sheet" ).Activate
  Range("B2" ).Select

End If

If FORMAT_SELECTED = 2 Then
  Worksheets("Data Input and Validation" ).Visible = xlVeryHidden
  Sheets("Data Entry Sheet" ).Visible = xlVeryHidden
  Sheets("Data Entry Sheet." ).Visible = True
  Worksheets("Data Entry Sheet." ).Activate
  Range("B2" ).Select

End If


Worksheets("Benchmarking Results" ).Range("B18" ).Value = TextBox1.Value
Worksheets("Benchmarking Results" ).Range("C18" ).Value = TextBox2.Value

Worksheets("Benchmarking Results" ).Visible = xlVeryHidden

Unload Me

MsgBox "Please enter your data (type or paste) into this sheet and click on the
Display cells' selection form tab. Then, click on required Sheet Cells and
corresponding Form Tabs. Once the four textboxes on the form are populated with the
required information, click OK." , vbOKOnly + vbInformation, "Information"


End Sub

Private Sub Label17_Click()


  Do While ComboBox15.Enabled = True Or _
      ComboBox16.Enabled = True Or _
      ComboBox17.Enabled = True

    Label20.Enabled = True
    Label21.Enabled = True
    Label37.Enabled = True

    ComboBox5.Enabled = True
    ComboBox6.Enabled = True
    ComboBox18.Enabled = True

    ComboBox15.Enabled = False
    ComboBox16.Enabled = False
    ComboBox17.Enabled = False

    Label34.Enabled = False
    Label35.Enabled = False
    Label36.Enabled = False

    ComboBox15.Value = "Select"
    ComboBox16.Value = "Select"
    ComboBox17.Value = "Select"
```

```
        ComboBox13.Clear
        ComboBox14.Clear
        ComboBox13.Value = KPI
        ComboBox14.Value = BENCHMARK_UNIT

        If ComboBox5.Text <> "Select"  And _
            ComboBox6.Text <> "Select"  And _
            ComboBox18.Text <> "Select"  Then
          INDUSTRIAL_SECTOR = Label17.Caption
        End If


    Loop

End Sub

Private Sub Label17_MouseMove(ByVal Button As Integer, ByVal Shift As Integer, ByVal x 
As Single, ByVal Y As Single)
    Label17.ForeColor = vbRed
End Sub

Private Sub Label33_Click()


    Do While ComboBox5.Enabled = True Or _
          ComboBox6.Enabled = True Or _
          ComboBox18.Enabled = True

        ComboBox5.Enabled = False
        ComboBox6.Enabled = False
        ComboBox18.Enabled = False

        ComboBox5.Value = "Select"
        ComboBox6.Value = "Select"
        ComboBox18.Value = "Select"

        ComboBox13.Clear
        ComboBox14.Clear
        ComboBox13.Value = KPI
        ComboBox14.Value = BENCHMARK_UNIT

        Label20.Enabled = False
        Label21.Enabled = False
        Label37.Enabled = False


        Label34.Enabled = True
        Label35.Enabled = True
        Label36.Enabled = True

        ComboBox15.Enabled = True
        ComboBox16.Enabled = True
        ComboBox17.Enabled = True

        If ComboBox15.Text <> "Select"  And _
            ComboBox16.Text <> "Select"  And _
            ComboBox17.Text <> "Select"  Then
          INDUSTRIAL_SECTOR = Label33.Caption
        End If
    Loop

End Sub

Private Sub Label33_MouseMove(ByVal Button As Integer, ByVal Shift As Integer, ByVal x 
As Single, ByVal Y As Single)
    Label33.ForeColor = vbRed
End Sub

Private Sub Select_Data_Arrangement_Format_Click()

    Application.ScreenUpdating = False
    Application.Interactive = False

    ActiveView = ActiveSheet.Name

    If ComboBox14.Text = "Select"  Or _
          ComboBox13.Text = "Select"  Then
        MsgBox "Some required entries are missing...please check!" , vbOKOnly + 
        vbExclamation, "Warning"
        Exit Sub
    End If
```

```
        Unload Me
        frm_DataSampleFormat1.Show

        Application.ScreenUpdating = True
        Application.Interactive = True

    End Sub

    Private Sub TextBox1_Change()

        If IsNumeric(TextBox1.Value) Then
            TextBox1.BackColor = vbWhite
            TextBox1.ForeColor = vbBlack
        Else
            TextBox1.BackColor = vbRed
            TextBox1.ForeColor = vbRed
            TextBox1.Value = ""
        End If

    End Sub
    Private Sub TextBox2_Change()
        If IsNumeric(TextBox1.Value) Then
            TextBox2.BackColor = vbWhite
            TextBox2.ForeColor = vbBlack
        Else
            TextBox2.BackColor = vbRed
            TextBox2.ForeColor = vbRed
            TextBox2.Value = ""
        End If

    End Sub

    Private Sub UserForm_Activate()

        Dim ActiveView As String
        Sheets("Home Page" ).Visible = True
        Sheets("Home page" ).Select
        ActiveView = ActiveSheet.Name
```

```
        txtBoxDummy.SetFocus

        If INDUSTRIAL_SECTOR = "Manufacturing"  Or INDUSTRIAL_SECTOR = ""  Then
            ComboBox5.Text = DIV_SEL
            ComboBox6.Text = SEG_SEL
            ComboBox18.Text = PROC_SEL
            ComboBox14.Text = BENCHMARK_UNIT
            ComboBox13.Text = KPI
            Call Label17_Click
        Else
            ComboBox15.Text = DIV_SEL
            ComboBox16.Text = SEG_SEL
            ComboBox17.Text = PROC_SEL
            ComboBox14.Text = BENCHMARK_UNIT
            ComboBox13.Text = KPI
            Call Label33_Click
        End If

        TextBox1.Value = Worksheets("Benchmarking Results" ).Range("B18" ).Value
        TextBox2.Value = Worksheets("Benchmarking Results" ).Range("C18" ).Value
    End Sub


    Private Sub UserForm_Terminate()
        Dim n As Long

        Application.ScreenUpdating = False
        Application.Interactive = False
        Sheets("Data input and Validation" ).Visible = True
```

```
                If IsEmpty(Cells(n, 1).Value) = True Then Exit For

                Cells(n, 23).Value = ""  'Remove Any Data
                Cells(n, 24).Value = ""  'Remove Any Data
            Next n
        End If
```

```
    'Sheets("Data input and Validation").Visible = xlSheetVeryHidden
    Application.ScreenUpdating = True
    Application.Interactive = True

    Sheets("Data input and Validation" ).Visible = xlSheetVeryHidden

    Sheets("Benchmarking results" ).Range("M49" ).Value = "Nb. If cells in the table
    above are highlighted in Red, then the corresponding sites use water above the
    average"
End Sub
```

9.1.15 frm_Contact_Information

frm_Contact_Information VBAProject

```
Private Sub Benchmarking_Results_Click()
  SELECTION_ORDER = 4
  If SELECTION_ORDER = 1 Or SELECTION_ORDER = 2 Or SELECTION_ORDER = 3 Then
  Else
    MsgBox "Each Benchmarking step follows an order. Please click on the
    Benchmarking Specifics label or Next tab to access the Data Input and Validation
    form. You will then be guided by the Wizard to the Benchmarking Results page." ,
    vbCritical + vbOKOnly, "Err Msg"
  End If

  If SELECTION_ORDER = 1 Or SELECTION_ORDER = 2 Or SELECTION_ORDER = 3 Then
    Unload Me
    Worksheets("Benchmarking Results" ).Activate
    Range("a1" ).Select
  End If
End Sub

Private Sub Benchmarking_Specifics_Click()
  Unload Me
  frm_Benchmarking_Specifics.Show
End Sub
Private Sub Benchmarking_Start_Form_Click()
  Unload Me
  frm_Benchmarking_Start_Form.Show
End Sub

Private Sub cmdCreateDate_Click()
  TextBox11.Text = Format(Now, "mm-dd-yyyy" ) & " "  & Format(Now, "hh:mm:ss" )
End Sub

Private Sub ComboBox2_Enter()

  ComboBox2.Clear

  ComboBox2.AddItem "Private"
  ComboBox2.AddItem "Government"
  ComboBox2.AddItem "Trade body"
  ComboBox2.AddItem "Academic Institution"
  ComboBox2.AddItem "Commercial Organisation"
  ComboBox2.AddItem "Water Company"
  ComboBox2.AddItem "Environmental Regulator"
  ComboBox2.AddItem "Others"

End Sub

Private Sub ComboBox2_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)
  KeyAscii = 0
End Sub

Private Sub ComboBox3_Enter()

  ComboBox3.Clear
  ComboBox3.AddItem "Afghanistan"
  ComboBox3.AddItem "Albania"
  ComboBox3.AddItem "Algeria"
  ComboBox3.AddItem "Andorra"
  ComboBox3.AddItem "Angola"
  ComboBox3.AddItem "Antigua and Barbuda"
  ComboBox3.AddItem "Argentina"
```

1

```
ComboBox3.AddItem "Armenia"
ComboBox3.AddItem "Australia"
ComboBox3.AddItem "Austria"
ComboBox3.AddItem "Azerbaijan"
ComboBox3.AddItem "Bahamas"
ComboBox3.AddItem "Bahrain"
ComboBox3.AddItem "Bangladesh"
ComboBox3.AddItem "Barbados"
ComboBox3.AddItem "Belarus"
ComboBox3.AddItem "Belgium"
ComboBox3.AddItem "Belize"
ComboBox3.AddItem "Benin"
ComboBox3.AddItem "Bhutan"
ComboBox3.AddItem "Bolivia"
ComboBox3.AddItem "Bosnia and Herzegovina"
ComboBox3.AddItem "Botswana"
ComboBox3.AddItem "Brazil"
ComboBox3.AddItem "Brunei"
ComboBox3.AddItem "Bulgaria"
ComboBox3.AddItem "Burkina Faso"
ComboBox3.AddItem "Burundi"
ComboBox3.AddItem "Cabo Verde"
ComboBox3.AddItem "Cambodia"
ComboBox3.AddItem "Cameroon"
ComboBox3.AddItem "Canada"
ComboBox3.AddItem "Central African Republic"
ComboBox3.AddItem "Chad"
ComboBox3.AddItem "Chile"
ComboBox3.AddItem "China"
ComboBox3.AddItem "Colombia"
ComboBox3.AddItem "Comoros"
ComboBox3.AddItem "Congo, Republic of the Congo"
ComboBox3.AddItem "Congo, Democratic Republic of the Congo"
ComboBox3.AddItem "Costa Rica"
ComboBox3.AddItem "Cote d'Ivoire"
ComboBox3.AddItem "Croatia"
ComboBox3.AddItem "Cuba"
ComboBox3.AddItem "Cyprus"
ComboBox3.AddItem "Czech Republic"
ComboBox3.AddItem "Denmark"
ComboBox3.AddItem "Djibouti"
ComboBox3.AddItem "Dominica"
ComboBox3.AddItem "Dominican Republic"
ComboBox3.AddItem "Ecuador"
ComboBox3.AddItem "Egypt"
ComboBox3.AddItem "El Salvador"
ComboBox3.AddItem "Equatorial Guinea"
ComboBox3.AddItem "Eritrea"
ComboBox3.AddItem "Estonia"
ComboBox3.AddItem "Ethiopia"
ComboBox3.AddItem "Fiji"
ComboBox3.AddItem "Finland"
ComboBox3.AddItem "France"
ComboBox3.AddItem "Gabon"
ComboBox3.AddItem "Gambia"
ComboBox3.AddItem "Georgia"
ComboBox3.AddItem "Germany"
ComboBox3.AddItem "Ghana"
ComboBox3.AddItem "Greece"
ComboBox3.AddItem "Grenada"
```

```
ComboBox3.AddItem "Guatemala"
ComboBox3.AddItem "Guinea"
ComboBox3.AddItem "Guinea-Bissau"
ComboBox3.AddItem "Guyana"
ComboBox3.AddItem "Haiti"
ComboBox3.AddItem "Honduras"
ComboBox3.AddItem "Hungary"
ComboBox3.AddItem "Iceland"
ComboBox3.AddItem "India"
ComboBox3.AddItem "Indonesia"
ComboBox3.AddItem "Iran"
ComboBox3.AddItem "Iraq"
ComboBox3.AddItem "Ireland"
```

```
ComboBox3.AddItem "Israel"
ComboBox3.AddItem "Italy"
ComboBox3.AddItem "Jamaica"
ComboBox3.AddItem "Japan"
ComboBox3.AddItem "Jordan"
ComboBox3.AddItem "Kazakhstan"
ComboBox3.AddItem "Kenya"
ComboBox3.AddItem "Kiribati"
ComboBox3.AddItem "Kosovo"
ComboBox3.AddItem "Kuwait"
ComboBox3.AddItem "Kyrgyzstan"
ComboBox3.AddItem "Laos"
ComboBox3.AddItem "Maldives"
ComboBox3.AddItem "Mali"
ComboBox3.AddItem "Malta"
ComboBox3.AddItem "Marshall Islands"
ComboBox3.AddItem "Mauritania"
ComboBox3.AddItem "Mauritius"
ComboBox3.AddItem "Mexico"
ComboBox3.AddItem "Micronesia"
ComboBox3.AddItem "Moldova"
ComboBox3.AddItem "Monaco"
ComboBox3.AddItem "Mongolia"
ComboBox3.AddItem "Montenegro"
ComboBox3.AddItem "Morocco"
ComboBox3.AddItem "Mozambique"
ComboBox3.AddItem "Myanmar (Burma)"
ComboBox3.AddItem "Namibia"
ComboBox3.AddItem "Nauru"
ComboBox3.AddItem "Nepal"
ComboBox3.AddItem "Netherlands"
ComboBox3.AddItem "New Zealand"
ComboBox3.AddItem "Nicaragua"
ComboBox3.AddItem "Niger"
ComboBox3.AddItem "Nigeria"
```

```
ComboBox3.AddItem "North Korea"
ComboBox3.AddItem "Norway"
ComboBox3.AddItem "Oman"
ComboBox3.AddItem "Pakistan"
ComboBox3.AddItem "Palau"
ComboBox3.AddItem "Palestine"
ComboBox3.AddItem "Panama"
ComboBox3.AddItem "Papua New Guinea"
ComboBox3.AddItem "Paraguay"
ComboBox3.AddItem "Peru"
ComboBox3.AddItem "Philippines"
ComboBox3.AddItem "Poland"
ComboBox3.AddItem "Portugal"
ComboBox3.AddItem "Qatar"
ComboBox3.AddItem "Romania"
ComboBox3.AddItem "Russia"
ComboBox3.AddItem "Rwanda"
ComboBox3.AddItem "St. Kitts and Nevis"
ComboBox3.AddItem "St. Lucia"
ComboBox3.AddItem "St. Vincent and The Grenadines"
ComboBox3.AddItem "Samoa"
ComboBox3.AddItem "San Marino"
ComboBox3.AddItem "Sao Tome and Principe"
ComboBox3.AddItem "Saudi Arabia"
ComboBox3.AddItem "Senegal"
ComboBox3.AddItem "Serbia"
ComboBox3.AddItem "Seychelles"
ComboBox3.AddItem "Sierra Leone"
ComboBox3.AddItem "Singapore"
ComboBox3.AddItem "Slovakia"
ComboBox3.AddItem "Slovenia"
ComboBox3.AddItem "Solomon Islands"
ComboBox3.AddItem "Somalia"
ComboBox3.AddItem "South Africa"
```

```
        ComboBox3.AddItem "South Korea"
        ComboBox3.AddItem "South Sudan"
        ComboBox3.AddItem "Spain"
        ComboBox3.AddItem "Sri Lanka"
        ComboBox3.AddItem "Sudan"
        ComboBox3.AddItem "Suriname"
        ComboBox3.AddItem "Swaziland"
        ComboBox3.AddItem "Sweden"
        ComboBox3.AddItem "Switzerland"
        ComboBox3.AddItem "Sweden"
        ComboBox3.AddItem "Switzerland"
        ComboBox3.AddItem "Syria"
        ComboBox3.AddItem "Taiwan"
        ComboBox3.AddItem "Tajikistan"
        ComboBox3.AddItem "Tanzania"
        ComboBox3.AddItem "Thailand"
        ComboBox3.AddItem "Timor-Leste"
        ComboBox3.AddItem "Togo"
        ComboBox3.AddItem "Tonga"
        ComboBox3.AddItem "Trinidad and Tobago"
        ComboBox3.AddItem "Tunisia"
        ComboBox3.AddItem "Turkey"
        ComboBox3.AddItem "Turkmenistan"
        ComboBox3.AddItem "Tuvalu"
        ComboBox3.AddItem "Uganda"
        ComboBox3.AddItem "Ukraine"
        ComboBox3.AddItem "United Arab Emirates"
        ComboBox3.AddItem "UK (United Kingdom)"
    1
    1
        ComboBox3.AddItem "USA (United States of America)"
        ComboBox3.AddItem "Uruguay"
        ComboBox3.AddItem "Uzbekistan"
        ComboBox3.AddItem "Vanuatu"
        ComboBox3.AddItem "Vatican City (Holy See)"
        ComboBox3.AddItem "Venezuela"
        ComboBox3.AddItem "Vietnam"
        ComboBox3.AddItem "Yemen"
        ComboBox3.AddItem "Zambia"
        ComboBox3.AddItem "Zimbabwe"

    End Sub
    Private Sub ComboBox3_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)
        KeyAscii = 0
    End Sub

    Private Sub Contact_Information_Click()
        Unload Me
        frm_Contact_Information.Show
    End Sub

    Private Sub Data_InputAndValidation_Click()
        SELECTION_ORDER = 3
        If SELECTION_ORDER = 1 Or SELECTION_ORDER = 2 Then
        Else
            MsgBox "Each Benchmarking step follows an order. Please click on the Next tab to
            access the Data Input and Validation form ..." , vbCritical + vbOKOnly, "Err
            Msg"
        End If

        If SELECTION_ORDER = 1 Or SELECTION_ORDER = 2 Then
            Unload Me
            Worksheets("Data input and Validation" ).Activate
            Range("a1" ).Select
        End If
    End Sub
    Private Sub Go_To_Benchmarking_Specifics_Click()

        Application.ScreenUpdating = False
        Application.Interactive = False

        Sheets("Benchmarking results" ).Visible = True
        Sheets("Benchmarking results" ).Select
```

```
    Range("D6" ).Value = ""  'Benchmarking Date
    Range("I6" ).Value = ""  'Company Name
    Range("I12" ).Value = ""  'Country
    Range("I11" ).Value = ""  'State
    Range("I7" ).Value = ""  'Branch/Site
    Range("I8" ).Value = ""  'Company Address
    Range("D9" ).Value = ""  'Company category
    Range("I9" ).Value = ""  'Zip/Post Code
    Range("D7" ).Value = ""  'Name of Benchmarking Staff
    Range("B8" ).Value = ""  'Name of Benchmarking Staff Others
    Range("I10" ).Value = ""  'Telephone
    Range("J14" ).Value = ""  'Notes

    Range("D6" ).Value = TextBox11.Text 'Benchmarking Date
    Range("I6" ).Value = TextBox4.Text 'Company Name
    Range("I12" ).Value = ComboBox3.Text 'Country
    Range("I11" ).Value = TextBox2001.Text 'State
    Range("I7" ).Value = TextBox5.Text 'Branch/Site
    Range("I8" ).Value = TextBox13.Text 'Company Address
    Range("D9" ).Value = ComboBox2.Text 'Company category
    Range("I9" ).Value = TextBox10.Text 'Zip/Post Code
    Range("D7" ).Value = TextBox6.Text 'Name of Benchmarking Staff
    Range("B8" ).Value = TextBox7.Text 'Name of Benchmarking Staff Others
    Range("I10" ).Value = TextBox12.Text 'Telephone
    Range("J14" ).Value = TextBox8.Text 'Notes

    Sheets("Benchmarking results" ).Visible = xlSheetVeryHidden
    Application.ScreenUpdating = True
    Application.Interactive = True

    Unload Me

    frm_Benchmarking_Specifics.Show
End Sub

Private Sub Return_To_Home_Page_Click()
    Unload Me
    Worksheets("Home Page" ).Activate
    Range("a1" ).Select
End Sub

Private Sub UserForm_Activate()

    Dim ActiveView As String

    ActiveView = ActiveSheet.Name

    Application.ScreenUpdating = False
    Application.Interactive = False

    TextBox11.Text = Sheets("Benchmarking results" ).Range("D6" ).Value 'Benchmarking
    Date
    TextBox4.Text = Sheets("Benchmarking results" ).Range("I6" ).Value 'Company Name
    ComboBox3.Text = Sheets("Benchmarking results" ).Range("I12" ).Value  'Country
    TextBox2001.Text = Sheets("Benchmarking results" ).Range("I11" ).Value 'State
    TextBox5.Text = Sheets("Benchmarking results" ).Range("I7" ).Value 'Branch/Site
    TextBox13.Text = Sheets("Benchmarking results" ).Range("I8" ).Value 'Company
    Address
    ComboBox2.Text = Sheets("Benchmarking results" ).Range("D9" ).Value 'Company
    category
    TextBox10.Text = Sheets("Benchmarking results" ).Range("I9" ).Value  'Zip/Post Code

    TextBox6.Text = Sheets("Benchmarking results" ).Range("D7" ).Value 'Name of
    Benchmarking Staff
    TextBox7.Text = Sheets("Benchmarking results" ).Range("B8" ).Value 'Name of
    Benchmarking Staff Others
    TextBox12.Text = Sheets("Benchmarking results" ).Range("I10" ).Value 'Telephone
    TextBox8.Text = Sheets("Benchmarking results" ).Range("J14" ).Value 'Notes

    Sheets(ActiveView).Select
    Application.ScreenUpdating = True
    Application.Interactive = True

End Sub
```

9.1.16 Mod_CHART_Functions

Mod_CHART_Functions VBAProject

```
Option Explicit
'----------------------------------------------------------------------------------------
'CHART Functions
'i-Water Benchmarking Tool v 1.00 (alpha)
'Year: 2015
'----------------------------------------------------------------------------------------
Public col_Index As Long
Public co2_Index As Long
Public bm_lo As Double
Public bm_hi As Double
Public bm_lo_exist As Boolean
Public bm_hi_exist As Boolean

Public Sub GetTable(targetSht As String, start_row As Long, start_col As Long, _
    retColl_XAxis As Collection, _
    retColl_Series As Collection, _
    k_Table As Data_Table)

  Dim n As Long
  Dim m As Long
  Dim last_row As Long


  Sheets(targetSht).Select
  'With Sheets(targetSht)
  'Get Series Names
  For n = start_col To start_col + 20
    If IsEmpty(Cells(11, n).Value) = True Then Exit For
    retColl_Series.Add Cells(11, n).Value
  Next n

  'Get X-Axis Values
  For n = start_row To Rows.Count
    If IsEmpty(Cells(n, 1).Value) = True Then Exit For
    retColl_XAxis.Add Cells(n, 1).Value
  Next n

  'Bench Mark Low/High
  If IsEmpty(Cells(12, 23).Value) = False Then
    bm_lo_exist = True
    bm_lo = Val(Cells(12, 23).Value)
  Else
    bm_lo_exist = False
  End If

  If IsEmpty(Cells(12, 24).Value) = False Then
    bm_hi_exist = True
    bm_hi = Val(Cells(12, 24).Value)
  Else
    bm_hi_exist = False
  End If

  last_row = n - 1
  n = 1
  'Get Data Values from Table
  Range(Cells(start_row, start_col + n - 1), Cells(last_row, start_col + 20 - 1)).
  Select
  k_Table.SeriesVal = Range(Cells(start_row, start_col + n - 1), Cells(last_row,

  start_col + 20 - 1)).Value

  'End With
End Sub

Public Sub TransferArrayC(k_Table As Data_Table, item_number As Long, x_SingleArray()
As Double)
  'Transfer a column of the Content of multi-dimensional array (i.e. range) into a
  single array

  Dim n As Long
```

```
        ReDim x_SingleArray(LBound(k_Table.SeriesVal) To UBound(k_Table.SeriesVal))

        For n = (LBound(k_Table.SeriesVal)) To (UBound(k_Table.SeriesVal))
            If k_Table.SeriesVal(n, item_number) = "" Or k_Table.SeriesVal(n, item_number) =
            "-" Then
                x_SingleArray(n) = 0
            Else
                x_SingleArray(n) = CStr(k_Table.SeriesVal(n, item_number))
            End If
        Next n

    End Sub

    Public Sub TransferArrayCl(k_Table As Data_Table, lower_bound As Long, upper_bound As
    Long, item_number As Long, x_SingleArray() As Double)

        'Transfer a column of the Content of multi-dimensional array (i.e. range) into a
        single array
        'Note:  This is for selected Sites only

        Dim n As Long

        ReDim x_SingleArray(lower_bound To upper_bound)

        For n = (LBound(k_Table.SeriesVal)) To (UBound(k_Table.SeriesVal))
            If n >= lower_bound And n <= upper_bound Then
                If k_Table.SeriesVal(n, item_number) = "" Or k_Table.SeriesVal(n, item_number
                ) = "-" Then
                    x_SingleArray(n) = 0
                Else
                    x_SingleArray(n) = CStr(k_Table.SeriesVal(n, item_number))
                End If
            End If
        Next n

    End Sub
    Public Sub TransferArrayR(k_Table As Data_Table, item_number As Long, x_SingleArray()
    As Double, Optional end_count As Long = 20)

        'Transfer a row of the Content of multi-dimensional array (i.e. range) into a
        single array

        Dim n As Long

        ReDim x_SingleArray(1 To end_count)

        For n = 1 To end_count
            If k_Table.SeriesVal(item_number, n) = "" Or k_Table.SeriesVal(item_number, n) =

            "-" Then
                x_SingleArray(n) = 0
            Else
                x_SingleArray(n) = CDbl(k_Table.SeriesVal(item_number, n))
            End If
        Next n

    End Sub

    Public Sub Update_Chart4(l_bound As Long, u_bound As Long)

        Dim n As Long
        Dim j As Long
        Dim x As Long

        'Collect Data from 'Data Input and Validation' Sheet
        Dim rX As New Collection         'x-Axis values (Chart 1), Series (Other Charts...)
        Dim rS As New Collection         'Series Collection Names (Chart 1), x-Axis values
        (Other Charts...)
        Dim kT As Data_Table             'Series Values (in an array/i.e. range)
        Dim series_data() As Double
        Dim series_names() As String

        'Dim l_bound As Long
        'Dim u_bound As Long

        'Get the data from 'Data input and Validation'
        GetTable "Data input and Validation" , 12, 2, rX, rS, kT
```

```
Sheets("Benchmarking results" ).Select
For n = 1 To ActiveSheet.Shapes.Count
  If InStr(ActiveSheet.Shapes(n).Name, "Chart" ) > 0 Then
    ActiveSheet.Shapes(n).Select
    'Chart 4 - Focused on Fewer Companies (or Sites)
    If InStr(ActiveChart.Name, "Chart 4" ) > 0 Then

      For x = 1 To rS.Count

        If x > ActiveChart.SeriesCollection.Count Then
          If IsEmpty(rS(x)) = True Then Exit For
          ActiveChart.SeriesCollection.NewSeries 'add new series
        End If

        'Choose First 5 (default) or up to maximum series count.
        'l_bound = 1
        'u_bound = 5
        If u_bound > rX.Count Then u_bound = rX.Count
        TransferArrayC1 kT, l_bound, u_bound, x, series_data

        ReDim x_axis_val(l_bound To u_bound)
        For j = 1 To rX.Count
          If j >= l_bound And j <= u_bound Then
            x_axis_val(j) = rX(j)
          End If
        Next j

        ActiveChart.SeriesCollection(x).XValues = x_axis_val 'x-Axis Values
        ActiveChart.SeriesCollection(x).Values = series_data 'series data
        ActiveChart.SeriesCollection(x).Name = rS(x)         'series name

        ActiveChart.SeriesCollection(x).ChartType = xlColumnClustered  'column
clustered
        ActiveChart.SeriesCollection(x).AxisGroup = 1        'primary axis

      Next x

      'Delete Excess Series
      If ActiveChart.SeriesCollection.Count > rS.Count Then
        For x = ActiveChart.SeriesCollection.Count To rS.Count + 1 Step -1
          ActiveChart.SeriesCollection(x).Delete
        Next x
      End If

      'Update Legend
      On Error Resume Next
      'Update Chart 4 series
      ActiveSheet.ChartObjects("Chart 4" ).Activate

      ActiveChart.SeriesCollection(1).Select
      With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(0, 128, 0)
        .BackColor.RGB = RGB(255, 255, 255)
        .Patterned msoPattern75Percent
      End With
      With Selection.Format.Fill
        .Visible = msoTrue
        .Patterned msoPattern75Percent
      End With
      Selection.Format.Line.Visible = msoFalse

      ActiveChart.SeriesCollection(2).Select
      With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(146, 208, 80)
        .Transparency = 0
        .Solid
      End With
      Selection.Format.Line.Visible = msoFalse

      ActiveChart.SeriesCollection(3).Select
      With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.ObjectThemeColor = msoThemeColorAccent6
        .ForeColor.TintAndShade = 0
        .ForeColor.Brightness = -0.25
        .Transparency = 0
        .Solid
      End With
      Selection.Format.Line.Visible = msoFalse
```

```
ActiveChart.SeriesCollection(4).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(56, 87, 35)
    .BackColor.RGB = RGB(255, 255, 255)
    .Patterned msoPatternDarkUpwardDiagonal
End With
With Selection.Format.Fill
    .Visible = msoTrue
    .Patterned msoPatternDarkUpwardDiagonal
End With

Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(5).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(0, 51, 0)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(6).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 51, 204)
    .BackColor.RGB = RGB(255, 255, 255)
    .Patterned msoPatternDarkUpwardDiagonal
End With
With Selection.Format.Fill
    .Visible = msoTrue
    .Patterned msoPatternDarkUpwardDiagonal
End With

Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(7).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 51, 204)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(8).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 153, 204)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(9).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 204, 255)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(10).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(112, 48, 160)
    .Transparency = 0
```

```
            .Solid
        End With
        Selection.Format.Line.Visible = msoFalse

        ActiveChart.SeriesCollection(11).Select

        With Selection.Format.Fill
            .Visible = msoTrue
            .PresetTextured msoTexturePapyrus
            .TextureTile = msoTrue
            .TextureOffsetX = 0
            .TextureOffsetY = 0
            .TextureHorizontalScale = 1
            .TextureVerticalScale = 1
            .TextureAlignment = msoTextureTopLeft
        End With
        Selection.Format.Line.Visible = msoFalse

        ActiveChart.SeriesCollection(12).Select
        With Selection.Format.Fill
            .Visible = msoTrue
            .PresetTextured msoTextureOak
            .TextureTile = msoTrue
            .TextureOffsetX = 0
            .TextureOffsetY = 0
            .TextureHorizontalScale = 1
            .TextureVerticalScale = 1
            .TextureAlignment = msoTextureTopLeft
        End With
        Selection.Format.Line.Visible = msoFalse

        ActiveChart.SeriesCollection(13).Select
        With Selection.Format.Fill
            .Visible = msoTrue
            .PresetTextured msoTextureMediumWood
            .TextureTile = msoTrue
            .TextureOffsetX = 0
            .TextureOffsetY = 0
            .TextureHorizontalScale = 1
            .TextureVerticalScale = 1
            .TextureAlignment = msoTextureTopLeft
        End With
        Selection.Format.Line.Visible = msoFalse

        ActiveChart.SeriesCollection(14).Select
        With Selection.Format.Fill
            .Visible = msoTrue
            .PresetTextured msoTextureWalnut
            .TextureTile = msoTrue
            .TextureOffsetX = 0
            .TextureOffsetY = 0
            .TextureHorizontalScale = 1
            .TextureVerticalScale = 1
            .TextureAlignment = msoTextureTopLeft
        End With
        Selection.Format.Line.Visible = msoFalse

        ActiveChart.SeriesCollection(15).Select
        With Selection.Format.Fill
            .Visible = msoTrue
            .ForeColor.RGB = RGB(102, 51, 0)
            .BackColor.RGB = RGB(255, 255, 255)
            .Patterned msoPatternDarkUpwardDiagonal
        End With
        With Selection.Format.Fill
            .Visible = msoTrue
            .Patterned msoPatternDarkUpwardDiagonal
        End With
        Selection.Format.Line.Visible = msoFalse

        ActiveChart.SeriesCollection(16).Select
        With Selection.Format.Fill
            .Visible = msoTrue
            .ForeColor.RGB = RGB(153, 102, 0)
            .Transparency = 0
            .Solid
        End With
        Selection.Format.Line.Visible = msoFalse
```

```
ActiveChart.SeriesCollection(17).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 153, 0)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(18).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 204, 0)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(19).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(204, 0, 0)
    .BackColor.RGB = RGB(255, 255, 255)
    .Patterned msoPatternDarkUpwardDiagonal
End With
With Selection.Format.Fill
    .Visible = msoTrue
    .Patterned msoPatternDarkUpwardDiagonal
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(20).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(204, 0, 0)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

'Update Bench Mark Limits

If bm_lo_exist = True Then
    'Add LL
    For x = LBound(x_axis_val) To UBound(x_axis_val)
        series_data(x) = bm_lo
    Next x

    ActiveChart.SeriesCollection.NewSeries 'add new series
    x = ActiveChart.SeriesCollection.Count
    ActiveChart.SeriesCollection(x).XValues = x_axis_val 'x-Axis Values
    ActiveChart.SeriesCollection(x).Values = series_data 'series data
    ActiveChart.SeriesCollection(x).Name = Worksheets("Data Input and Validation" ).Range("W11" ).Value            'series name

    If LBound(x_axis_val) = UBound(x_axis_val) _
        And Worksheets("Data Input and Validation" ).Range("W12" ).Value <> "" Then
        ActiveChart.SeriesCollection(x).ChartType = xlLineMarkers
        ActiveChart.SeriesCollection(x).Select

        With Selection
            .MarkerStyle = 3
            .MarkerSize = 7
        End With

        Selection.MarkerStyle = -4118

        With Selection.Format.Fill
            .Visible = msoTrue
            .ForeColor.RGB = RGB(0, 0, 255)
        End With

        With Selection.Format.Line
            .Visible = msoTrue
            .ForeColor.RGB = RGB(0, 0, 255)
            .Weight = 0.5
        End With
```

```
                Else
                    ActiveChart.SeriesCollection(x).ChartType = xlLine
                End If

                ActiveChart.SeriesCollection(x).Format.Line.ForeColor.RGB = RGB(0, 0,
                255) 'Blue
                ActiveChart.SeriesCollection(x).AxisGroup = 2
            End If

            If bm_hi_exist = True Then
                'Add UL
                For x = LBound(x_axis_val) To UBound(x_axis_val)
                    series_data(x) = bm_hi
                Next x
                ActiveChart.SeriesCollection.NewSeries 'add new series
                x = ActiveChart.SeriesCollection.Count
                ActiveChart.SeriesCollection(x).XValues = x_axis_val 'x-Axis Values
                ActiveChart.SeriesCollection(x).Values = series_data 'series data
                ActiveChart.SeriesCollection(x).Name = Worksheets("Data Input and
                Validation" ).Range("X11" ).Value              'series name

                If LBound(x_axis_val) = UBound(x_axis_val) _
                    And Worksheets("Data Input and Validation" ).Range("X12" ).Value <>
                    "" Then
                    ActiveChart.SeriesCollection(x).ChartType = xlLineMarkers
                    ActiveChart.SeriesCollection(x).Select

                    With Selection
                        .MarkerStyle = 3
                        .MarkerSize = 7
                    End With

                    Selection.MarkerStyle = -4118

                    With Selection.Format.Fill
                        .Visible = msoTrue
                        .ForeColor.RGB = RGB(255, 0, 0)
                        '.Transparency = 0
                        '.Solid
                    End With

                    With Selection.Format.Line
                        .Visible = msoTrue
                        .ForeColor.RGB = RGB(255, 0, 0)
                        .Weight = 0.5
                    End With

                Else
                    ActiveChart.SeriesCollection(x).ChartType = xlLine
                End If

                ActiveChart.SeriesCollection(x).Format.Line.ForeColor.RGB = RGB(255, 0,
                0) 'Red
                ActiveChart.SeriesCollection(x).AxisGroup = 2
            End If

        End If
    End If
  Next n
  Range("A1" ).Select
End Sub

Public Sub Update_Chart5(l_bound As Long, u_bound As Long, period_sel_index As Long)

    Dim n As Long
    Dim j As Long
    Dim x As Long

    'Collect Data from 'Data Input and Validation' Sheet
    Dim rX As New Collection        'x-Axis values (Chart 1), Series (Other Charts...)
    Dim rS As New Collection        'Series Collection Names (Chart 1), x-Axis values
    (Other Charts...)
    Dim kT As Data_Table            'Series Values (in an array/i.e. range)
    Dim series_data() As Double
    Dim series_names() As String
```

```
    'Get the data from 'Data input and Validation'
    GetTable "Data input and Validation" , 12, 2, rX, rS, kT

    Sheets("Benchmarking results" ).Select
    For n = 1 To ActiveSheet.Shapes.Count

        If InStr(ActiveSheet.Shapes(n).Name, "Chart" ) > 0 Then
            ActiveSheet.Shapes(n).Select

            'Chart 5 - Focused on Fewer Companies (or Sites)
            If InStr(ActiveChart.Name, "Chart 5" ) > 0 Then

                For x = 1 To rS.Count

                    If x > ActiveChart.SeriesCollection.Count Then
                        If IsEmpty(rS(x)) = True Then Exit For
                        ActiveChart.SeriesCollection.NewSeries 'add new series
                    End If

                    'Choose First 5 (default) or up to maximum series count.
                    If u_bound > rX.Count Then u_bound = rX.Count
                    TransferArrayC1 kT, l_bound, u_bound, period_sel_index, series_data
                    'Earliest Date Default

                    ReDim x_axis_val(l_bound To u_bound)

                    For j = 1 To rX.Count
                        If j >= l_bound And j <= u_bound Then
                            x_axis_val(j) = rX(j)
                        End If
                    Next j

                    ActiveChart.SeriesCollection(x).XValues = x_axis_val 'x-Axis Values
                    ActiveChart.SeriesCollection(x).Values = series_data 'series data
                    ActiveChart.SeriesCollection(x).Name = rS(x)          'series name

                Next x

                'Delete Excess Series
                If ActiveChart.SeriesCollection.Count > rS.Count Then
                    For x = ActiveChart.SeriesCollection.Count To rS.Count + 1 Step -1
                        ActiveChart.SeriesCollection(x).Delete
                    Next x
                End If

                'Update Legend
                ActiveChart.SetElement (msoElementLegendNone)
                'ActiveChart.SetElement (msoElementLegendTop)

                ActiveChart.ChartTitle.Text = rS(period_sel_index)

            End If
        End If
    Next n
    Range("A1" ).Select
End Sub

Public Sub Update_Charts()

    Dim n As Long
    Dim j As Long
    Dim x As Long

    'Collect Data from 'Data Input and Validation' Sheet
    Dim rX As New Collection 'x-Axis values (Chart 1), Series (Other Charts...)
    Dim rS As New Collection 'Series Collection Names (Chart 1), x-Axis values (Other
    Charts...)
    Dim kT As Data_Table      'Series Values (in an array/i.e. range)
    Dim series_data() As Double
    Dim series_names() As String

    Dim l_bound As Long
    Dim u_bound As Long

    'Get the data from 'Data input and Validation'
    GetTable "Data input and Validation" , 12, 2, rX, rS, kT
```

```
Sheets("Benchmarking results" ).Select

For n = 1 To ActiveSheet.Shapes.Count
  If InStr(ActiveSheet.Shapes(n).Name, "Chart" ) > 0 Then
    ActiveSheet.Shapes(n).Select

    'Chart 2 - Site on X-Axis, Date as Series
    If InStr(ActiveChart.Name, "Chart 2" ) > 0 Then

      ReDim x_axis_val(1 To rX.Count)
      For j = 1 To rX.Count
        x_axis_val(j) = rX(j)
      Next j

      For x = 1 To rS.Count

        If x > ActiveChart.SeriesCollection.Count Then
          If IsEmpty(rS(x)) = True Then Exit For
          ActiveChart.SeriesCollection.NewSeries                  'add new
          series
        End If

        TransferArrayC kT, x, series_data
        'FieldSpecify1

        ActiveChart.SeriesCollection(x).XValues = x_axis_val          'x-Axis
        Values
        ActiveChart.SeriesCollection(x).Values = series_data          'series
        data
        ActiveChart.SeriesCollection(x).Name = rS(x)                  'series
        name
        ActiveChart.SeriesCollection(x).ChartType = xlColumnClustered 'column
        clustered
        ActiveChart.SeriesCollection(x).AxisGroup = 1
        'primary axis

      Next x

      'Delete Excess Series
      If ActiveChart.SeriesCollection.Count > rS.Count Then
        For x = ActiveChart.SeriesCollection.Count To rS.Count + 1 Step -1
          ActiveChart.SeriesCollection(x).Delete
        Next x
      End If

      'Update Legend
      'Enhance the graphical representation of the chart series
      On Error Resume Next

      'Update Chart 2 series
      ActiveSheet.ChartObjects("Chart 2" ).Activate

      ActiveChart.SeriesCollection(1).Select
      With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(0, 128, 0)
        .BackColor.RGB = RGB(255, 255, 255)
        .Patterned msoPattern75Percent
      End With
      With Selection.Format.Fill
        .Visible = msoTrue
        .Patterned msoPattern75Percent
      End With
      Selection.Format.Line.Visible = msoFalse

      ActiveChart.SeriesCollection(2).Select
      With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(146, 208, 80)
        .Transparency = 0
        .Solid
      End With
      Selection.Format.Line.Visible = msoFalse
```

```
ActiveChart.SeriesCollection(3).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.ObjectThemeColor = msoThemeColorAccent6
    .ForeColor.TintAndShade = 0
    .ForeColor.Brightness = -0.25
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(4).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(56, 87, 35)
    .BackColor.RGB = RGB(255, 255, 255)
    .Patterned msoPatternDarkUpwardDiagonal
End With
With Selection.Format.Fill
    .Visible = msoTrue
    .Patterned msoPatternDarkUpwardDiagonal
End With

Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(5).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(0, 51, 0)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(6).Select
1 2 3 4
1 2 3 4
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 51, 204)
    .BackColor.RGB = RGB(255, 255, 255)
    .Patterned msoPatternDarkUpwardDiagonal
End With
With Selection.Format.Fill
    .Visible = msoTrue
    .Patterned msoPatternDarkUpwardDiagonal
End With

Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(7).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 51, 204)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(8).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 153, 204)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(9).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 204, 255)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse
```

```
ActiveChart.SeriesCollection(10).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(112, 48, 160)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(11).Select

With Selection.Format.Fill
    .Visible = msoTrue
    .PresetTextured msoTexturePapyrus
    .TextureTile = msoTrue
    .TextureOffsetX = 0
    .TextureOffsetY = 0
    .TextureHorizontalScale = 1
    .TextureVerticalScale = 1
    .TextureAlignment = msoTextureTopLeft
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(12).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .PresetTextured msoTextureOak
    .TextureTile = msoTrue
    .TextureOffsetX = 0
    .TextureOffsetY = 0
    .TextureHorizontalScale = 1
    .TextureVerticalScale = 1
    .TextureAlignment = msoTextureTopLeft
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(13).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .PresetTextured msoTextureMediumWood
    .TextureTile = msoTrue
    .TextureOffsetX = 0
    .TextureOffsetY = 0
    .TextureHorizontalScale = 1
    .TextureVerticalScale = 1
    .TextureAlignment = msoTextureTopLeft
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(14).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .PresetTextured msoTextureWalnut
    .TextureTile = msoTrue
    .TextureOffsetX = 0
    .TextureOffsetY = 0
    .TextureHorizontalScale = 1
    .TextureVerticalScale = 1
    .TextureAlignment = msoTextureTopLeft
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(15).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(102, 51, 0)
    .BackColor.RGB = RGB(255, 255, 255)
    .Patterned msoPatternDarkUpwardDiagonal
End With
With Selection.Format.Fill
    .Visible = msoTrue
    .Patterned msoPatternDarkUpwardDiagonal
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(16).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(153, 102, 0)
    .Transparency = 0
```

```
1 2 3 4 5
        .Solid
    End With
    Selection.Format.Line.Visible = msoFalse

    ActiveChart.SeriesCollection(17).Select
    With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(255, 153, 0)
        .Transparency = 0
        .Solid
    End With
    Selection.Format.Line.Visible = msoFalse

    ActiveChart.SeriesCollection(18).Select
    With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(255, 204, 0)
        .Transparency = 0
        .Solid
    End With
    Selection.Format.Line.Visible = msoFalse

    ActiveChart.SeriesCollection(19).Select
    With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(204, 0, 0)
        .BackColor.RGB = RGB(255, 255, 255)
        .Patterned msoPatternDarkUpwardDiagonal
    End With
    With Selection.Format.Fill
        .Visible = msoTrue
        .Patterned msoPatternDarkUpwardDiagonal
    End With
    Selection.Format.Line.Visible = msoFalse

    ActiveChart.SeriesCollection(20).Select
    With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(204, 0, 0)
        .Transparency = 0
        .Solid
    End With
    Selection.Format.Line.Visible = msoFalse

    'Update Bench Mark Limits
    If bm_lo_exist = True Then
        'Add LL
        For x = LBound(x_axis_val) To UBound(x_axis_val)
            series_data(x) = bm_lo
        Next x

        ActiveChart.SeriesCollection.NewSeries
                                                               'add
        new series
        x = ActiveChart.SeriesCollection.Count
        ActiveChart.SeriesCollection(x).XValues = x_axis_val
                                                   'x-Axis Values
        ActiveChart.SeriesCollection(x).Values = series_data
                                                   'series data
        ActiveChart.SeriesCollection(x).Name = Worksheets("Data Input and
1 2 3 4 5
1 2 3 4 5
        Validation" ).Range("W11" ).Value     'series name
        ActiveChart.SeriesCollection(x).ChartType = xlLine
        ActiveChart.SeriesCollection(x).Format.Line.ForeColor.RGB = RGB(0, 0,
        255)                                'Blue
        ActiveChart.SeriesCollection(x).AxisGroup = 2

        If Worksheets("Data Input and Validation" ).Range("B13" ).Value = "" _
            And Worksheets("Data Input and Validation" ).Range("W12" ).Value <>
           ""  Then
            ActiveChart.SeriesCollection(x).ChartType = xlLineMarkers
            ActiveChart.SeriesCollection(x).Select

            With Selection
                .MarkerStyle = 3
                .MarkerSize = 7
            End With
```

```
Selection.MarkerStyle = -4118

With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(0, 0, 255)
End With

With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(0, 0, 255)
    .Weight = 0.5
End With

Else
    ActiveChart.SeriesCollection(x).ChartType = xlLine
End If

End If

If bm_hi_exist = True Then

    'Check if the benchmark limits are reproduced down to the selected
    limit, if not, populate the required cells
    Worksheets("Data input and Validation" ).Select
    Range("W13" ).Select
    ActiveCell.FormulaR1C1 = _
    "=IF(ISBLANK(R[-1]C)," "" ",IF(ISBLANK(RC1)," "" ",R[-1]C))"
    Range("X13" ).Select
    ActiveCell.FormulaR1C1 = _
    "=IF(ISBLANK(R[-1]C)," "" ",IF(ISBLANK(RC1)," "" ",R[-1]C))"
    Range("W13:X13" ).Select
    Selection.AutoFill Destination:=Range("W13:X62" ), Type:=xlFillDefault
    Range("W13:X62" ).Select
    Sheets("Benchmarking results" ).Select

    'Add UL
    For x = LBound(x_axis_val) To UBound(x_axis_val)
        series_data(x) = bm_hi
    Next x
    ActiveChart.SeriesCollection.NewSeries
                                                            'add new
    series
    x = ActiveChart.SeriesCollection.Count
1 2 3 4 5
1 2 3 4 5
    ActiveChart.SeriesCollection(x).XValues = x_axis_val
                                                  'x-Axis Values
    ActiveChart.SeriesCollection(x).Values = series_data
                                                  'series data
    ActiveChart.SeriesCollection(x).Name = Worksheets("Data Input and
    Validation" ).Range("X11" ).Value    'series name
    ActiveChart.SeriesCollection(x).ChartType = xlLine
    ActiveChart.SeriesCollection(x).Format.Line.ForeColor.RGB = RGB(255, 0,
    0)                      'Red
    ActiveChart.SeriesCollection(x).AxisGroup = 2

    If Worksheets("Data Input and Validation" ).Range("B13" ).Value = ""  _
        And Worksheets("Data Input and Validation" ).Range("X12" ).Value <>
        ""  Then
        ActiveChart.SeriesCollection(x).ChartType = xlLineMarkers
        ActiveChart.SeriesCollection(x).Select

        With Selection
            .MarkerStyle = 3
            .MarkerSize = 7
        End With

        Selection.MarkerStyle = -4118

        With Selection.Format.Fill
            .Visible = msoTrue
            .ForeColor.RGB = RGB(255, 0, 0)
        End With

        With Selection.Format.Line
            .Visible = msoTrue
            .ForeColor.RGB = RGB(255, 0, 0)
            .Weight = 0.5
        End With
```

```
                Else
                    ActiveChart.SeriesCollection(x).ChartType = xlLine
                End If

                ' Stretch each benchmark (Upper and Lower - were applicable) to the
                ends of the chart

                ActiveSheet.ChartObjects("Chart 2" ).Activate
                ActiveChart.SetElement (msoElementSecondaryValueAxisShow)
                ActiveChart.Axes(xlValue, xlSecondary).Select
                Selection.Delete
                ActiveSheet.ChartObjects("Chart 2" ).Activate
                ActiveChart.PlotArea.Select
                ActiveChart.SetElement (msoElementSecondaryCategoryAxisShow)
                ActiveChart.Axes(xlCategory, xlSecondary).Select
                Selection.TickLabelPosition = xlNone
                Selection.MajorTickMark = xlNone
                ActiveChart.Axes(xlCategory, xlSecondary).AxisBetweenCategories = False
                Selection.Format.Fill.Visible = msoFalse
                Selection.Format.Line.Visible = msoFalse

            End If

        End If

        'Chart 3 - Date on X-Axis, Site/Company as Series
        If InStr(ActiveChart.Name, "Chart 3" ) > 0 Then
            ReDim x_axis_val(1 To rS.Count)
            For j = 1 To rS.Count
                x_axis_val(j) = rS(j)
            Next j

            For x = 1 To rX.Count
                If x > ActiveChart.SeriesCollection.Count Then
                    If IsEmpty(rX(x)) = True Then Exit For
                    ActiveChart.SeriesCollection.NewSeries            'add new series
                End If

                TransferArrayR kT, x, series_data, rS.Count          'FieldSpecify2
                (Chart 2)?

                ActiveChart.SeriesCollection(x).XValues = x_axis_val 'x-axis Values
                ActiveChart.SeriesCollection(x).Values = series_data 'series data
                ActiveChart.SeriesCollection(x).Name = rX(x)         'series name

            Next x

            'Delete Excess Series
            If ActiveChart.SeriesCollection.Count > rX.Count Then
                For x = ActiveChart.SeriesCollection.Count To rX.Count + 1 Step -1
                    ActiveChart.SeriesCollection(x).Delete
                Next x
            End If

            'Update Legend

            On Error Resume Next
            ActiveSheet.ChartObjects("Chart 3" ).Activate

            ActiveChart.SeriesCollection(1).Select
            With Selection.Format.Line
                .Visible = msoTrue
                .ForeColor.RGB = RGB(0, 255, 160)
                .Transparency = 0
                .Solid
            End With
            With Selection
                .MarkerStyle = 1
                .MarkerSize = 5
            End With
            Selection.Format.Fill.Visible = msoFalse


            ActiveChart.SeriesCollection(2).Select
            With Selection.Format.Line
                .Visible = msoTrue
                .ForeColor.RGB = RGB(140, 0, 50)
                .Transparency = 0
                .Solid
            End With
            With Selection
                .MarkerStyle = 2
                .MarkerSize = 5
            End With
            Selection.Format.Fill.Visible = msoFalse
```

```
ActiveChart.SeriesCollection(3).Select
With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(240, 13, 206)
    .Transparency = 0
    .Solid
End With
With Selection
    .MarkerStyle = 3
    .MarkerSize = 5
End With
Selection.Format.Fill.Visible = msoFalse

ActiveChart.SeriesCollection(4).Select
With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(170, 127, 145)
    .Transparency = 0
    .Solid
End With
With Selection
    .MarkerStyle = 5
    .MarkerSize = 5
End With
Selection.Format.Fill.Visible = msoFalse

ActiveChart.SeriesCollection(5).Select
With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(180, 112, 200)
    .Transparency = 0
    .Solid
End With
With Selection
    .MarkerStyle = 8
    .MarkerSize = 5
End With
Selection.Format.Fill.Visible = msoFalse

ActiveChart.SeriesCollection(6).Select
With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(139, 205, 255)
    .Transparency = 0
    .Solid
End With
With Selection
    .MarkerStyle = 9
    .MarkerSize = 5
End With
Selection.Format.Fill.Visible = msoFalse

ActiveChart.SeriesCollection(7).Select
With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(200, 176, 240)
    .Transparency = 0
    .Solid
End With
```

```
With Selection
    .MarkerStyle = 1
    .MarkerSize = 5
End With
Selection.Format.Fill.Visible = msoFalse

ActiveChart.SeriesCollection(8).Select
With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(189, 238, 0)
    .Transparency = 0
    .Solid
End With
With Selection
    .MarkerStyle = 2
    .MarkerSize = 5
End With
Selection.Format.Fill.Visible = msoFalse
```

```
ActiveChart.SeriesCollection(9).Select
With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(50, 126, 80)
    .Transparency = 0
    .Solid
End With
With Selection
    .MarkerStyle = 3
    .MarkerSize = 5
End With
Selection.Format.Fill.Visible = msoFalse

ActiveChart.SeriesCollection(10).Select
With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(143, 255, 194)
    .Transparency = 0
    .Solid
End With
With Selection
    .MarkerStyle = 5
    .MarkerSize = 5
End With
Selection.Format.Fill.Visible = msoFalse

ActiveChart.SeriesCollection(11).Select
With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(146, 208, 80)
    .Transparency = 0
    .Solid
End With
With Selection
    .MarkerStyle = 8
    .MarkerSize = 5
End With
Selection.Format.Fill.Visible = msoFalse

ActiveChart.SeriesCollection(12).Select
With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(100, 220, 9)
    .Transparency = 0
    .Solid
End With
With Selection
    .MarkerStyle = 9
    .MarkerSize = 5
End With
Selection.Format.Fill.Visible = msoFalse

ActiveChart.SeriesCollection(13).Select
With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 255, 0)
    .Transparency = 0
    .Solid
End With
With Selection
    .MarkerStyle = 1
    .MarkerSize = 5
End With
Selection.Format.Fill.Visible = msoFalse

ActiveChart.SeriesCollection(14).Select
With Selection.Format.Line
    .Visible = msoTrue
    .ForeColor.RGB = RGB(204, 233, 173)
    .Transparency = 0
    .Solid
End With
With Selection
    .MarkerStyle = 2
    .MarkerSize = 5
End With
Selection.Format.Fill.Visible = msoFalse
```

```
        ActiveChart.SeriesCollection(15).Select
        With Selection.Format.Line
            .Visible = msoTrue
            .ForeColor.RGB = RGB(200, 140, 100)
            .Transparency = 0
            .Solid
        End With
        With Selection
            .MarkerStyle = 3
            .MarkerSize = 5
        End With
        Selection.Format.Fill.Visible = msoFalse

        ActiveChart.SeriesCollection(16).Select
        With Selection.Format.Line
            .Visible = msoTrue
            .ForeColor.RGB = RGB(220, 190, 0)
            .Transparency = 0
            .Solid
        End With
        With Selection
            .MarkerStyle = 5
            .MarkerSize = 5
        End With
        Selection.Format.Fill.Visible = msoFalse

        ActiveChart.SeriesCollection(17).Select
        With Selection.Format.Line
            .Visible = msoTrue
            .ForeColor.RGB = RGB(150, 27, 190)
            .Transparency = 0
            .Solid
        End With
        With Selection
            .MarkerStyle = 8
            .MarkerSize = 5
        End With
        Selection.Format.Fill.Visible = msoFalse

        ActiveChart.SeriesCollection(18).Select
        With Selection.Format.Line
            .Visible = msoTrue
            .ForeColor.RGB = RGB(112, 14, 6)
            .Transparency = 0
            .Solid
        End With
        With Selection
            .MarkerStyle = 9
            .MarkerSize = 5
        End With
        Selection.Format.Fill.Visible = msoFalse

        ActiveChart.SeriesCollection(19).Select
        With Selection.Format.Line
            .Visible = msoTrue
            .ForeColor.RGB = RGB(0, 200, 6)
            .Transparency = 0
            .Solid
        End With
        With Selection
            .MarkerStyle = 1
            .MarkerSize = 5
        End With
        Selection.Format.Fill.Visible = msoFalse

        ActiveChart.SeriesCollection(20).Select
        With Selection.Format.Line
            .Visible = msoTrue
            .ForeColor.RGB = RGB(94, 92, 26)
            .Transparency = 0
            .Solid
        End With
        With Selection
            .MarkerStyle = 2
            .MarkerSize = 5
        End With
        Selection.Format.Fill.Visible = msoFalse
```

```
                'Update Bench Mark Limits
                If bm_lo_exist = True Then

                    'Add LL
                    For x = LBound(x_axis_val) To UBound(x_axis_val)
                        series_data(x) = bm_lo
                    Next x

                    ActiveChart.SeriesCollection.NewSeries                                          'add new series
                    x = ActiveChart.SeriesCollection.Count
                    ActiveChart.SeriesCollection(x).XValues = x_axis_val                            'x-Axis Values
                    ActiveChart.SeriesCollection(x).Values = series_data                            'series data
                    ActiveChart.SeriesCollection(x).Name = Worksheets("Data Input and Validation").Range("W11").Value   'series name
                    ActiveChart.SeriesCollection(x).Format.Line.ForeColor.RGB = RGB(0, 0, 255)      'Blue

                End If

                If bm_hi_exist = True Then
                    'Add UL
                    For x = LBound(x_axis_val) To UBound(x_axis_val)
                        series_data(x) = bm_hi
                    Next x
                    ActiveChart.SeriesCollection.NewSeries                                          'add new series
                    x = ActiveChart.SeriesCollection.Count
                    ActiveChart.SeriesCollection(x).XValues = x_axis_val                            'x-Axis Values
                    ActiveChart.SeriesCollection(x).Values = series_data                            'series data
                    ActiveChart.SeriesCollection(x).Name = Worksheets("Data Input and Validation").Range("X11").Value   'series name
                    ActiveChart.SeriesCollection(x).Format.Line.ForeColor.RGB = RGB(255, 0, 0)      'Blue

                End If

            End If

            'Chart 4 - Focused on Fewer Companies (or Sites)
            If InStr(ActiveChart.Name, "Chart 4") > 0 Then

                For x = 1 To r8.Count

                    If x > ActiveChart.SeriesCollection.Count Then
                        If IsEmpty(r8(x)) = True Then Exit For
                        ActiveChart.SeriesCollection.NewSeries                  'add new series
                    End If

                    'Choose First 5 (default) or up to maximum series count.
                    l_bound = 1
                    u_bound = rX.Count
                    'If u_bound > rX.Count Then u_bound = rX.Count
                    TransferArrayC1 kT, l_bound, u_bound, x, series_data

                    ReDim x_axis_val(l_bound To u_bound)
                    For j = 1 To rX.Count
                        If j >= l_bound And j <= u_bound Then
                            x_axis_val(j) = rX(j)
                        End If
                    Next j

                    ActiveChart.SeriesCollection(x).XValues = x_axis_val                'x-Axis Values
                    ActiveChart.SeriesCollection(x).Values = series_data                'series data
                    ActiveChart.SeriesCollection(x).Name = r8(x)                        'series name
                    ActiveChart.SeriesCollection(x).ChartType = xlColumnClustered       'column clustered
                    ActiveChart.SeriesCollection(x).AxisGroup = 1                       'primary axis

                Next x
```

```
'Delete Excess Series
If ActiveChart.SeriesCollection.Count > rS.Count Then
   For x = ActiveChart.SeriesCollection.Count To rS.Count + 1 Step -1
      ActiveChart.SeriesCollection(x).Delete
   Next x
End If

'Update Legend

'Update Bench Mark Limits
If bm_lo_exist = True Then
   'Add LL
   For x = LBound(x_axis_val) To UBound(x_axis_val)
      series_data(x) = bm_lo
   Next x

   ActiveChart.SeriesCollection.NewSeries
                                                               'add new
   series
   x = ActiveChart.SeriesCollection.Count
   ActiveChart.SeriesCollection(x).XValues = x_axis_val
                                                  'x-Axis Values
   ActiveChart.SeriesCollection(x).Values = series_data
                                                  'series data
   ActiveChart.SeriesCollection(x).Name = Worksheets("Data Input and
   Validation").Range("W11").Value   'series name
   ActiveChart.SeriesCollection(x).ChartType = xlLine
   ActiveChart.SeriesCollection(x).AxisGroup = 2
End If

If bm_hi_exist = True Then
   'Add UL
   For x = LBound(x_axis_val) To UBound(x_axis_val)
      series_data(x) = bm_hi
   Next x
   ActiveChart.SeriesCollection.NewSeries
                                                               'add new
   series
   x = ActiveChart.SeriesCollection.Count
   ActiveChart.SeriesCollection(x).XValues = x_axis_val
                                                  'x-Axis Values
   ActiveChart.SeriesCollection(x).Values = series_data
                                                  'series data

   ActiveChart.SeriesCollection(x).Name = Worksheets("Data Input and
   Validation").Range("X11").Value   'series name
   ActiveChart.SeriesCollection(x).ChartType = xlLine
   ActiveChart.SeriesCollection(x).AxisGroup = 2

End If

End If

'Chart 5 - Focused on Fewer Companies (or Sites) and specific period only!
If InStr(ActiveChart.Name, "Chart 5") > 0 Then

   For x = 1 To rS.Count

      If x > ActiveChart.SeriesCollection.Count Then
         If IsEmpty(rS(x)) = True Then Exit For
         ActiveChart.SeriesCollection.NewSeries 'add new series
      End If

      'Choose First 5 (default) or up to maximum series count.
      l_bound = 1
      u_bound = 10
      If u_bound > rX.Count Then u_bound = rX.Count
      TransferArrayC1 kT, l_bound, u_bound, x, series_data   'Earliest Date
      Default

      ReDim x_axis_val(l_bound To u_bound)
      For j = 1 To rX.Count
         If j >= l_bound And j <= u_bound Then
            x_axis_val(j) = rX(j)
         End If
      Next j

      ActiveChart.SeriesCollection(x).XValues = x_axis_val 'x-Axis Values
      ActiveChart.SeriesCollection(x).Values = series_data 'series data
      ActiveChart.SeriesCollection(x).Name = rS(x)         'series name

   Next x
```

```
                'Delete Excess Series
                If ActiveChart.SeriesCollection.Count > r8.Count Then
                  For x = ActiveChart.SeriesCollection.Count To r8.Count + 1 Step -1
                    ActiveChart.SeriesCollection(x).Delete
                  Next x
                End If

                'Update Legend
                ActiveChart.SetElement (msoElementLegendNone)

                ActiveChart.ChartTitle.Text = r8(r8.Count)

              End If
            End If
          Next n

          'Enhance the graphical representation of the chart series
          On Error Resume Next
          'Update Chart 5 series
          ActiveSheet.ChartObjects("Chart 5" ).Activate

 1

 1
          ActiveChart.SeriesCollection(1).Points(1).Select
          With Selection.Format.Fill
            .Visible = msoTrue
            .ForeColor.RGB = RGB(0, 128, 0)
            .BackColor.RGB = RGB(255, 255, 255)
            .Patterned msoPattern75Percent
          End With
          With Selection.Format.Fill
            .Visible = msoTrue
            .Patterned msoPattern75Percent
          End With
          Selection.Format.Line.Visible = msoFalse

          ActiveChart.SeriesCollection(1).Points(2).Select
          With Selection.Format.Fill
            .Visible = msoTrue
            .ForeColor.RGB = RGB(146, 208, 80)
            .Transparency = 0
            .Solid
          End With
          Selection.Format.Line.Visible = msoFalse

          ActiveChart.SeriesCollection(1).Points(3).Select
          With Selection.Format.Fill
            .Visible = msoTrue
            .ForeColor.ObjectThemeColor = msoThemeColorAccent6
            .ForeColor.TintAndShade = 0
            .ForeColor.Brightness = -0.25
            .Transparency = 0
            .Solid
          End With
          Selection.Format.Line.Visible = msoFalse

          ActiveChart.SeriesCollection(1).Points(4).Select
          With Selection.Format.Fill
            .Visible = msoTrue
            .ForeColor.RGB = RGB(56, 87, 35)
            .BackColor.RGB = RGB(255, 255, 255)
            .Patterned msoPatternDarkUpwardDiagonal
          End With
          With Selection.Format.Fill
            .Visible = msoTrue
            .Patterned msoPatternDarkUpwardDiagonal
          End With

          Selection.Format.Line.Visible = msoFalse

          ActiveChart.SeriesCollection(1).Points(5).Select
          With Selection.Format.Fill
            .Visible = msoTrue
            .ForeColor.RGB = RGB(0, 51, 0)
            .Transparency = 0
            .Solid
          End With
          Selection.Format.Line.Visible = msoFalse

          ActiveChart.SeriesCollection(1).Points(6).Select
          With Selection.Format.Fill
            .Visible = msoTrue
            .ForeColor.RGB = RGB(255, 51, 204)
 1 2
```

```
        .BackColor.RGB = RGB(255, 255, 255)
        .Patterned msoPatternDarkUpwardDiagonal
    End With
    With Selection.Format.Fill
        .Visible = msoTrue
        .Patterned msoPatternDarkUpwardDiagonal
    End With

    Selection.Format.Line.Visible = msoFalse

    ActiveChart.SeriesCollection(1).Points(7).Select
    With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(255, 51, 204)
        .Transparency = 0
        .Solid
    End With
    Selection.Format.Line.Visible = msoFalse

    ActiveChart.SeriesCollection(1).Points(8).Select
    With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(255, 153, 204)
        .Transparency = 0
        .Solid
    End With
    Selection.Format.Line.Visible = msoFalse

    ActiveChart.SeriesCollection(1).Points(9).Select
    With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(255, 204, 255)
        .Transparency = 0
        .Solid
    End With
    Selection.Format.Line.Visible = msoFalse

    ActiveChart.SeriesCollection(1).Points(10).Select
    With Selection.Format.Fill
        .Visible = msoTrue
        .ForeColor.RGB = RGB(112, 48, 160)
        .Transparency = 0
        .Solid
    End With
    Selection.Format.Line.Visible = msoFalse

    ActiveChart.SeriesCollection(1).Points(11).Select

    With Selection.Format.Fill
        .Visible = msoTrue
        .PresetTextured msoTexturePapyrus
        .TextureTile = msoTrue
        .TextureOffsetX = 0
        .TextureOffsetY = 0
        .TextureHorizontalScale = 1
        .TextureVerticalScale = 1
        .TextureAlignment = msoTextureTopLeft
    End With
    Selection.Format.Line.Visible = msoFalse


    ActiveChart.SeriesCollection(1).Points(12).Select
    With Selection.Format.Fill
        .Visible = msoTrue
        .PresetTextured msoTextureOak
        .TextureTile = msoTrue
        .TextureOffsetX = 0
        .TextureOffsetY = 0
        .TextureHorizontalScale = 1
        .TextureVerticalScale = 1
        .TextureAlignment = msoTextureTopLeft
    End With
    Selection.Format.Line.Visible = msoFalse
```

```
ActiveChart.SeriesCollection(1).Points(13).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .PresetTextured msoTextureMediumWood
    .TextureTile = msoTrue
    .TextureOffsetX = 0
    .TextureOffsetY = 0
    .TextureHorizontalScale = 1
    .TextureVerticalScale = 1
    .TextureAlignment = msoTextureTopLeft
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(1).Points(14).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .PresetTextured msoTextureWalnut
    .TextureTile = msoTrue
    .TextureOffsetX = 0
    .TextureOffsetY = 0
    .TextureHorizontalScale = 1
    .TextureVerticalScale = 1
    .TextureAlignment = msoTextureTopLeft
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(1).Points(15).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(102, 51, 0)
    .BackColor.RGB = RGB(255, 255, 255)
    .Patterned msoPatternDarkUpwardDiagonal
End With
With Selection.Format.Fill
    .Visible = msoTrue
    .Patterned msoPatternDarkUpwardDiagonal
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(1).Points(16).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(153, 102, 0)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse
1 2
1 2

ActiveChart.SeriesCollection(1).Points(17).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 153, 0)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(1).Points(18).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(255, 204, 0)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

ActiveChart.SeriesCollection(1).Points(19).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(204, 0, 0)
    .BackColor.RGB = RGB(255, 255, 255)
    .Patterned msoPatternDarkUpwardDiagonal
End With
With Selection.Format.Fill
    .Visible = msoTrue
    .Patterned msoPatternDarkUpwardDiagonal
End With
Selection.Format.Line.Visible = msoFalse
```

```
ActiveChart.SeriesCollection(1).Points(20).Select
With Selection.Format.Fill
    .Visible = msoTrue
    .ForeColor.RGB = RGB(204, 0, 0)
    .Transparency = 0
    .Solid
End With
Selection.Format.Line.Visible = msoFalse

' Check error
On Error Resume Next

If Worksheets("Benchmarking results" ).Range("D15" ).Value <> ""  Then

    ActiveSheet.ChartObjects("Chart 2" ).Activate
    ActiveChart.Axes(xlValue).AxisTitle.Select
    ActiveChart.Axes(xlValue, xlPrimary).AxisTitle.Text = Worksheets("Benchmarking results" ).Range("D15" ).Value
    ActiveSheet.ChartObjects("Chart 3" ).Activate
    ActiveChart.Axes(xlValue).AxisTitle.Select
    ActiveChart.Axes(xlValue, xlPrimary).AxisTitle.Text = Worksheets("Benchmarking results" ).Range("D15" ).Value
    ActiveSheet.ChartObjects("Chart 4" ).Activate
    ActiveChart.Axes(xlValue).AxisTitle.Select
    ActiveChart.Axes(xlValue, xlPrimary).AxisTitle.Text = Worksheets("Benchmarking results" ).Range("D15" ).Value

End If
1 2
1 2



If Worksheets("Benchmarking results" ).Range("D14" ).Value <> "Water Use (Absolute)" _
    And Worksheets("Benchmarking results" ).Range("D15" ).Value <> ""  Then

    ActiveSheet.ChartObjects("Chart 2" ).Activate
    ActiveChart.Axes(xlValue).AxisTitle.Select
    ActiveChart.Axes(xlValue, xlPrimary).AxisTitle.Text = Worksheets("Benchmarking results" ).Range("D15" ).Value
    ActiveSheet.ChartObjects("Chart 3" ).Activate
    ActiveChart.Axes(xlValue).AxisTitle.Select
    ActiveChart.Axes(xlValue, xlPrimary).AxisTitle.Text = Worksheets("Benchmarking results" ).Range("D15" ).Value
    ActiveSheet.ChartObjects("Chart 4" ).Activate
    ActiveChart.Axes(xlValue).AxisTitle.Select
    ActiveChart.Axes(xlValue, xlPrimary).AxisTitle.Text = Worksheets("Benchmarking results" ).Range("D15" ).Value


    ActiveSheet.ChartObjects("Chart 2" ).Activate
    ActiveChart.Axes(xlValue).AxisTitle.Select
    ActiveChart.Axes(xlValue, xlPrimary).AxisTitle.Text = Worksheets("Benchmarking results" ).Range("D15" ).Value

    With Selection.Format.TextFrame2.TextRange.Characters(1, 6).ParagraphFormat
        .TextDirection = msoTextDirectionLeftToRight
        .Alignment = msoAlignCenter
    End With

    With Selection.Format.TextFrame2.TextRange.Characters(1, 6).Font
        .BaselineOffset = 0
        .Bold = msoFalse
        .NameComplexScript = "Verdana"
        .NameFarEast = "Verdana"
        .Fill.Visible = msoTrue
        .Fill.ForeColor.RGB = RGB(0, 0, 0)
        .Fill.Transparency = 0
        .Fill.Solid
        .Size = 6
        .Italic = msoFalse
        .Kerning = 12
        .Name = "Verdana"
        .UnderlineStyle = msoNoUnderline
        .Strike = msoNoStrike
    End With
```

```
            ActiveSheet.ChartObjects("Chart 3" ).Activate
            ActiveChart.Axes(xlValue).AxisTitle.Select
            ActiveChart.Axes(xlValue, xlPrimary).AxisTitle.Text = Worksheets("Benchmarking
            results" ).Range("D15" ).Value

            With Selection.Format.TextFrame2.TextRange.Characters(1, 6).ParagraphFormat
                .TextDirection = msoTextDirectionLeftToRight
                .Alignment = msoAlignCenter
            End With

            With Selection.Format.TextFrame2.TextRange.Characters(1, 6).Font
                .BaselineOffset = 0
                .Bold = msoFalse
                .NameComplexScript = "Verdana"
                .NameFarEast = "Verdana"
                .Fill.Visible = msoTrue
                .Fill.ForeColor.RGB = RGB(0, 0, 0)
                .Fill.Transparency = 0
                .Fill.Solid
                .Size = 6
                .Italic = msoFalse
                .Kerning = 12
                .Name = "Verdana"
                .UnderlineStyle = msoNoUnderline
                .Strike = msoNoStrike
            End With

            ActiveSheet.ChartObjects("Chart 4" ).Activate
            ActiveChart.Axes(xlValue).AxisTitle.Select
            ActiveChart.Axes(xlValue, xlPrimary).AxisTitle.Text = Worksheets("Benchmarking
            results" ).Range("D15" ).Value

            With Selection.Format.TextFrame2.TextRange.Characters(1, 6).ParagraphFormat
                .TextDirection = msoTextDirectionLeftToRight
                .Alignment = msoAlignCenter
            End With

            With Selection.Format.TextFrame2.TextRange.Characters(1, 6).Font
                .BaselineOffset = 0
                .Bold = msoFalse
                .NameComplexScript = "Verdana"
                .NameFarEast = "Verdana"
                .Fill.Visible = msoTrue
                .Fill.ForeColor.RGB = RGB(0, 0, 0)
                .Fill.Transparency = 0
                .Fill.Solid
                .Size = 6
                .Italic = msoFalse
                .Kerning = 12
                .Name = "Verdana"
                .UnderlineStyle = msoNoUnderline
                .Strike = msoNoStrike

            End With
        End If

        Range("A1" ).Select

    End Sub

    Public Sub UpdateList()

        Dim a As Long
        Dim b As Long

        Dim n As Long
        Dim SiteN As String
        Dim SiteNAve As String
        Dim SiteLL As Double
        Dim SiteUL As Double

        'Clean up all characters and texts (strings)
```

```
Dim d As Range
Dim kl As Range

Application.ScreenUpdating = False
Worksheets("Data input and Validation" ).Visible = True

Worksheets("Data input and Validation" ).Select
Range("B12:U62" ).Select
For Each kl In Range("B12:U62" )
  If kl.Value Like "*[!0-9,.,,,]*"  Or IsNumeric(kl.Value) = False Then
    kl.Value = ""
    kl.Interior.Color = vbWhite  'RGB(255, 0, 0)
    kl.Font.Color = vbBlack
  End If
Next
Worksheets("Data input and Validation" ).Range("B12:U62" ).Select
Selection.Interior.Color = vbWhite  'RGB(255, 0, 0)
Selection.Font.Color = vbBlack


Call Update_Charts
frm_Config_Charts.Show vbModal

Sheets("Benchmarking results" ).Select
Range("M29:X49" ).ClearContents
Range("M29:X49" ).Interior.Color = vbWhite


'Get the Average consumption per Site
a = 0
b = 0
For n = 12 To Rows.Count
  Sheets("Data input and Validation" ).Select
  If IsEmpty(Cells(n, 1).Value) = True Then Exit For

  a = a + 1
  If b >= 20 Then Exit For 'should not exceed more than 20 comparison in the table


  If a >= col_Index And a <= co2_Index Then
    b = b + 1 'increment counter for site selected
    SiteN = Cells(n, 1).Value
    SiteNAve = Cells(n, 25).Value
    SiteLL = Val(Cells(n, 23).Value)
    SiteUL = Val(Cells(n, 24).Value)

    Sheets("Benchmarking results" ).Select
    Cells(28 + b, 13).Value = SiteN
    Cells(28 + b, 14).Value = SiteNAve
    Cells(28 + b, 17).Value = SiteLL  'Use only the Lower limit for the
    calculation rather than both - (SiteLL + SiteUL) / 2
    If Val(SiteNAve) <> 0 Then
      Cells(28 + b, 20).Value = Val(SiteNAve) - SiteLL
      Cells(28 + b, 21).Value = Format((Val(SiteNAve) - (SiteLL)) / Val(SiteNAve)
      , "0.0%" )

      Worksheets("Benchmarking results" ).Select
      If Range("D15" ).Value <> ""  And Range("D15" ).Value <> "%"  And Range(
      "D15" ).Value <> "% of water consumption for entire production"  And Range(
      "D15" ).Value <> "% of water consumption"  Then

        If Range("D15" ).Value = "hl/hl"  Or Range("D15" ).Value = "hl/hl beer"
         Or Range("D15" ).Value = "hl water/hl beer sold"  Or Range("D15" ).
        Value = "hl/hl beer sold"  Then
          'Convert hl to litres using 1 hectolitre = 0.1 cubic metres
          Cells(28 + b, 22).Value = ((Val(SiteNAve) - SiteLL) * 0.1) * (
          Worksheets("Benchmarking Results" ).Range("B18" ).Value)
          Cells(28 + b, 23).Value = ((Val(SiteNAve) - SiteLL) * 0.1) * (
          Worksheets("BenchmarkingResults" ).Range("C18" ).Value)
        End If
```

```
If Range("D15" ).Value = "kg/t raw material"  Or Range("D15" ).Value =
"kg/t MBM"  Or Range("D15" ).Value = "kg/t unrefined oil"  Or Range(
"D15" ).Value = "kg/tonne"  Then

  'Convert kg to litres using 1 kg = 0.001 cubic metres
  Cells(28 + b, 22).Value = ((Val(SiteNAve) - SiteLL) * 0.001) * (
  Worksheets("Benchmarking Results" ).Range("B18" ).Value)

  Cells(28 + b, 23).Value = ((Val(SiteNAve) - SiteLL) * 0.001) * (
  Worksheets("Benchmarking Results" ).Range("C18" ).Value)
End If
Worksheets("Benchmarking results" ).Select
If Range("D15" ).Value = "Litre(s)/bird"  Or Range("D15" ).Value =
"Litres"  Or Range("D15" ).Value = "Litre(s)/animal"  _
    Or Range("D15" ).Value = "Litre(s)/kg of bird"  Or Range("D15" ).
  Value = "Litre(s)/t turkey carcass"  _
    Or Range("D15" ).Value = "Litre(s)/kg slaughtered animal"  Or Range
  ("D15" ).Value = "Litre(s)/stomach"  _
    Or Range("D15" ).Value = "Litre(s)/tray"  Or Range("D15" ).Value =
  "Litre(s)/t pig carcass"  _
    Or Range("D15" ).Value = "Litre(s)/pig"  Or Range("D15" ).Value =
  "Litre(s)/h"  _
    Or Range("D15" ).Value = "Litre(s)/pig intestine"  Or Range("D15" )
  .Value = "Litre(s)/t of carcass"  _
    Or Range("D15" ).Value = "Litre(s)/head"  Or Range("D15" ).Value =
  "Litre(s)/t poultry carcass"  Or _
    Range("D15" ).Value = "Litre(s)/carcass"  Or Range("D15" ).Value =
  "Litre(s)/t sheep carcass"  Or _
    Range("D15" ).Value = "Litre(s)/tonne"  Or Range("D15" ).Value =
  "Litre(s)/t cattle carcass"  _
    Or Range("D15" ).Value = "Litre(s)/t raw material"  Or Range("D15"
  ).Value = "Litre(s)/t by-product rendered"  _
    Or Range("D15" ).Value = "Litre(s)/t blood"  Or Range("D15" ).Value
   = "Litre(s)/t feather and hair rendered"  _
    Or Range("D15" ).Value = "Litre(s)/t fish treated"  Or Range("D15"
  ).Value = "Litre(s)/t"  _
    Or Range("D15" ).Value = "Litre(s)/t soap"  Or Range("D15" ).Value
  = "Litre/kg product"  _
    Or Range("D15" ).Value = "Litre(s)/litre of received milk"  Or
  Range("D15" ).Value = "Litre(s)/litre processed milk"  _
    Or Range("D15" ).Value = "Litre(s)/litre raw material"  Or Range(
  "D15" ).Value = "Litre(s)/litre received milk"  _
    Or Range("D15" ).Value = "Litre(s)/litre"  Or Range("D15" ).Value =
   "Litre(s)/kg processed milk"  _
    Or Range("D15" ).Value = "Litre(s)/flush"  Or Range("D15" ).Value =
   "Litre(s)/litre of product"  Or Range("D15" ).Value =
  "Litre(s)/bottle"  _
    Or Range("D15" ).Value = "Litre(s)/t cheese"  Or Range("D15" ).
  Value = "Litre(s)/hl"  Or _
    Range("D15" ).Value = "Litre(s)/litre of Finished beverage"  Or
  Range("D15" ).Value = "Litre(s)/litre of processed milk"  _
    Or Range("D15" ).Value = "Litre(s)/t raw coffee"  Or Range("D15" ).
  Value = "Litre(s)/kg ice cream"  _
    Or Range("D15" ).Value = "Litre(s)/kg of produced ice cream"  Or
  Range("D15" ).Value = "Litre(s)/litre of Beer"  _
    Or Range("D15" ).Value = "Litre(s)/kg product"  Or Range("D15" ).
  Value = "Litre(s)/KWh of Electricity generated"  Then

  'Convert litre to cubic metres using 1 litre = 0.001 cubic metres
  Cells(28 + b, 22).Value = ((Val(SiteNAve) - SiteLL) * 0.001) * (
  Worksheets("Benchmarking Results" ).Range("B18" ).Value)
  If Range("D10" ).Value <> "Thermoelectric Power"  Then
    Cells(28 + b, 23).Value = ((Val(SiteNAve) - SiteLL) * 0.001) * (
    Worksheets("Benchmarking Results" ).Range("C18" ).Value)
  End If
End If


If Range("D15" ).Value = "m³/t of finished product"  Or Range("D15" ).
Value = "m³/tonne carcass"  _
    Or Range("D15" ).Value = "m³/tonne of product"  Or Range("D15" ).
  Value = "m³/t"  Or _
    Range("D15" ).Value = "m³/tonne"  Or Range("D15" ).Value = "m³/yr"
   Or Range("D15" ).Value = "m³/tonne of raw material"  _
    Or Range("D15" ).Value = "m³/t of product"  Or Range("D15" ).Value
  = "m³"  Or Range("D15" ).Value = "m³/t oil seed"  Or _
    Range("D15" ).Value = "m³/t oil"  Or Range("D15" ).Value = "m³/t
  of oil"  Or _
```

```
    Range("D15" ).Value = "m³/t of olive oil produced"  Or Range("D15"
 ).Value = "m³/t unrefined oil"  Or _
    Range("D15" ).Value = "m³/liter"  Or Range("D15" ).Value = "m³/t
 raw milk"  Or Range("D15" ).Value = "m³/kg"  Or _
    Range("D15" ).Value = "m³/t of pasta"  Or Range("D15" ).Value =
 "m³/m³ of product"  Or _
    Range("D15" ).Value = "m³/hl of beer produced"  Or Range("D15" ).
 Value = "m³/t DDGS produced"  Or _
    Range("D15" ).Value = "m³/m³"  Or Range("D15" ).Value = "m³/tonne
 cane"  Or Range("D15" ).Value = "m³/t sugar produced"  _
    Or Range("D15" ).Value = "m³/t board"  Or Range("D15" ).Value =
 "m³/t of paper"  Or Range("D15" ).Value = "m³/tonne of product"  Then

 Cells(28 + b, 22).Value = (Val(SiteNAve) - SiteLL) * (Worksheets(
 "Benchmarking Results" ).Range("B18" ).Value)
 If Range("D10" ).Value <> "Thermoelectric Power"  Then
    Cells(28 + b, 23).Value = (Val(SiteNAve) - SiteLL) * (Worksheets(
    "Benchmarking Results" ).Range("C18" ).Value)
 End If
End If
End If

If Worksheets("Benchmarking results" ).Range("D14" ).Value = "Water Use
per Unit Product (Relative)"  Then
 If Range("N29" ).Value <> ""  And Range("Q29" ).Value <> ""  Then
   If Range("N29" ).Value > Range("Q29" ).Value Then
     Range("M29" ).Interior.Color = vbRed
     Range("T29" ).Interior.Color = vbRed
1 2 3 4 5 6 7
1 2 3 4 5 6 7
   End If
 End If

 If Range("N30" ).Value <> ""  And Range("Q30" ).Value <> ""  Then
   If Range("N30" ).Value > Range("Q30" ).Value Then
     Range("M30" ).Interior.Color = vbRed
     Range("T30" ).Interior.Color = vbRed
   End If
 End If

 If Range("N31" ).Value <> ""  And Range("Q31" ).Value <> ""  Then
   If Range("N31" ).Value > Range("Q31" ).Value Then
     Range("M31" ).Interior.Color = vbRed
     Range("T31" ).Interior.Color = vbRed
   End If
 End If

 If Range("N32" ).Value <> ""  And Range("Q32" ).Value <> ""  Then
   If Range("N32" ).Value > Range("Q32" ).Value Then
     Range("M32" ).Interior.Color = vbRed
     Range("T32" ).Interior.Color = vbRed
   End If
 End If

 If Range("N33" ).Value <> ""  And Range("Q33" ).Value <> 0 Then
   If Range("N33" ).Value > Range("Q33" ).Value Then
     Range("M33" ).Interior.Color = vbRed
     Range("T33" ).Interior.Color = vbRed
   End If
 End If

 If Range("N34" ).Value <> ""  And Range("Q34" ).Value <> ""  Then
   If Range("N34" ).Value > Range("Q34" ).Value Then
     Range("M34" ).Interior.Color = vbRed
     Range("T34" ).Interior.Color = vbRed
   End If
 End If

 If Range("N35" ).Value <> ""  And Range("Q35" ).Value <> ""  Then
   If Range("N35" ).Value > Range("Q35" ).Value Then
     Range("M35" ).Interior.Color = vbRed
     Range("T35" ).Interior.Color = vbRed
   End If
 End If

 If Range("N36" ).Value <> ""  And Range("Q36" ).Value <> ""  Then
   If Range("N36" ).Value > Range("Q36" ).Value Then
     Range("M36" ).Interior.Color = vbRed
     Range("T36" ).Interior.Color = vbRed
   End If
 End If
```

```
If Range("N37" ).Value <> ""  And Range("Q37" ).Value <> ""  Then
 If Range("N37" ).Value > Range("Q37" ).Value Then
  Range("M37" ).Interior.Color = vbRed
  Range("T37" ).Interior.Color = vbRed
 End If
End If

If Range("N38" ).Value <> ""  And Range("Q38" ).Value <> ""  Then
 If Range("N38" ).Value > Range("Q38" ).Value Then
  Range("M38" ).Interior.Color = vbRed
  Range("T38" ).Interior.Color = vbRed
 End If
End If

If Range("N39" ).Value <> ""  And Range("Q39" ).Value <> ""  Then
 If Range("N39" ).Value > Range("Q39" ).Value Then
  Range("M39" ).Interior.Color = vbRed
  Range("T39" ).Interior.Color = vbRed
 End If
End If

If Range("N40" ).Value <> ""  And Range("Q40" ).Value <> ""  Then
 If Range("N40" ).Value > Range("Q40" ).Value Then
  Range("M40" ).Interior.Color = vbRed
  Range("T40" ).Interior.Color = vbRed
 End If
End If

If Range("N41" ).Value <> ""  And Range("Q41" ).Value <> ""  Then
 If Range("N41" ).Value > Range("Q41" ).Value Then
  Range("M41" ).Interior.Color = vbRed
  Range("T41" ).Interior.Color = vbRed
 End If
End If

If Range("N42" ).Value <> ""  And Range("Q42" ).Value <> ""  Then
 If Range("N42" ).Value > Range("Q42" ).Value Then
  Range("M42" ).Interior.Color = vbRed
  Range("T42" ).Interior.Color = vbRed
 End If
End If

If Range("N43" ).Value <> ""  And Range("Q43" ).Value <> ""  Then
 If Range("N43" ).Value > Range("Q43" ).Value Then
  Range("M43" ).Interior.Color = vbRed
  Range("T43" ).Interior.Color = vbRed
 End If
End If

If Range("N44" ).Value <> ""  And Range("Q44" ).Value <> ""  Then
 If Range("N44" ).Value > Range("Q44" ).Value Then
  Range("M44" ).Interior.Color = vbRed
  Range("T44" ).Interior.Color = vbRed
 End If
End If

If Range("N45" ).Value <> ""  And Range("Q45" ).Value <> ""  Then
 If Range("N45" ).Value > Range("Q45" ).Value Then
  Range("M45" ).Interior.Color = vbRed
  Range("T45" ).Interior.Color = vbRed
 End If
End If

If Range("N46" ).Value <> ""  And Range("Q46" ).Value <> ""  Then
 If Range("N46" ).Value > Range("Q46" ).Value Then
  Range("M46" ).Interior.Color = vbRed
  Range("T46" ).Interior.Color = vbRed
 End If
End If

If Range("N47" ).Value <> ""  And Range("Q47" ).Value <> ""  Then
 If Range("N47" ).Value > Range("Q47" ).Value Then
  Range("M47" ).Interior.Color = vbRed
  Range("T47" ).Interior.Color = vbRed
 End If
End If

If Range("N48" ).Value <> ""  And Range("Q48" ).Value <> ""  Then
 If Range("N48" ).Value > Range("Q48" ).Value Then
  Range("M48" ).Interior.Color = vbRed
  Range("T48" ).Interior.Color = vbRed
 End If
End If

End If

End If
End If
Next n
```

```
Sheets("Benchmarking results" ).Select
Application.ScreenUpdating = True

If bm_hi_exist = True Or bm_lo_exist = True Then
  Call Remove_Sec_Axis_from_Chart4
Else
  Range("A1" ).Select
End If

'Enhance the graphical representation of the chart series

'Rank sites in the order of their water use intensities, 1 = Highest
Worksheets("Benchmarking Results" ).Select

If Range("N29" ) <> ""  Then
  Range("P29" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If

If Range("N30" ) <> ""  Then
  Range("P30" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If

If Range("N31" ) <> ""  Then
  Range("P31" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If
If Range("N32" ) <> ""  Then
  Range("P32" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If

If Range("N33" ) <> ""  Then
  Range("P33" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If

1 2
1 2
If Range("N34" ) <> ""  Then
  Range("P34" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If

If Range("N35" ) <> ""  Then
  Range("P35" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If

If Range("N36" ) <> ""  Then
  Range("P36" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If

If Range("N37" ) <> ""  Then
  Range("P37" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If
If Range("N38" ) <> ""  Then
  Range("P38" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If

If Range("N39" ) <> ""  Then
  Range("P39" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If

If Range("N40" ) <> ""  Then
  Range("P40" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If
If Range("N41" ) <> ""  Then
  Range("P41" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If

If Range("N42" ) <> ""  Then
  Range("P42" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If

If Range("N43" ) <> ""  Then
  Range("P43" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If
If Range("N44" ) <> ""  Then
  Range("P44" ).Select
  ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
End If
```

```
        If Range("N45" ) <> ""  Then
            Range("P45" ).Select
            ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
        End If

        If Range("N46" ) <> ""  Then
            Range("P46" ).Select
            ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
        End If

        If Range("N47" ) <> ""  Then
            Range("P47" ).Select
            ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
        End If

        If Range("N48" ) <> ""  Then
            Range("P48" ).Select
            ActiveCell.FormulaR1C1 = "=RANK(RC[-2],R29C14:R48C14,0)"
        End If

        Sheets("Benchmarking results" ).Range("M49" ).Value = "Nb. If cells in the table
        above are highlighted in Red, then the corresponding sites use water above the
        average"

        Application.ScreenUpdating = True

    End Sub
```

9.1.17 Mod_MAIN_Functions

Mod_MAIN_Functions VBAProject

```
'MAIN Functions
'i-Water Benchmarking Tool v 1.00
'Year: 2015
'-----------------------------------------------------------------------------------------


Public FORMAT_SELECTED As Long
Public INDUSTRIAL_SECTOR As String
Public DIV_SEL As String
Public SEG_SEL As String
Public PROC_SEL As String
Public ROW_SEL As Long
Public BENCHMARK_UL As Double
Public BENCHMARK_LL As Double
Public BENCHMARK_INDEX As Long
Public DATA_VALIDATION As Long
Public SELECTION_ORDER As Long


Public BenchMark_UL_List As New Collection
Public BenchMark_LL_List As New Collection
Public BENCHMARK_UNIT As String
Public KPI As String
Public Type Data_Table
  SeriesVal() As Variant
End Type

Public Function CheckValidPeriod(Entry As String) As Boolean

  Dim n As Long
  Dim xStr() As String
  Dim MonthString As String
  MonthString =
  "January,February,March,April,May,June,July,August,September,October,November,Decembe
  r"

  'Check if Format is Year
  If Val(Entry) > 1000 And Val(Entry) < 9999 Then
    CheckValidPeriod = True

  ElseIf Trim(Entry) = ""  Then
    CheckValidPeriod = False
```

```
        'Check if Format is Month
    ElseIf InStr(MonthString, Entry) > 0 Then
        CheckValidPeriod = True

    ElseIf InStr(Entry, "/" ) Then
        'Check if Format is (xx/yy)
        xStr = Split(Entry, "/" )

        For n = LBound(xStr) To UBound(xStr)
            If IsNumeric(xStr(n)) = False Then
                If InStr(MonthString, xStr(n)) = 0 Then
                    CheckValidPeriod = False
                Else
                    CheckValidPeriod = True
1 2 3 4 5
1 2 3 4 5
                End If
            Else
                CheckValidPeriod = True
            End If
        Next n

    ElseIf InStr(Entry, "-" ) Then
        'Check if Format is (xx-yy)
        xStr = Split(Entry, "-" )
        For n = LBound(xStr) To UBound(xStr)
            If IsNumeric(xStr(n)) = False Then
                If InStr(MonthString, xStr(n)) = 0 Then
                    CheckValidPeriod = False
                Else
                    CheckValidPeriod = True
                End If
            Else
                CheckValidPeriod = True
            End If
        Next n

    Else
        CheckValidPeriod = False
    End If

End Function

Public Sub Display_FieldSpecify_1()
    Dim row_1 As Long
    Dim col_1 As Long

    'Check if the sheet is empty or not
    If Cells(2, 1).Value <> ""  Then
        If MsgBox("This sheet has data! Do you want to clear the data first?" , vbYesNo +
        vbQuestion, "Warning" ) = vbYes Then
            For row_1 = 2 To Rows.Count
                If IsEmpty(Cells(row_1, 1).Value) = True Then Exit For
                For col_1 = 1 To Columns.Count
                    If IsEmpty(Cells(row_1, col_1).Value) = True Then Exit For
                    Cells(row_1, col_1).Value = ""  'clear entry on that cell
                    Worksheets("Data Entry Sheet" ).Range("B2:U52" ).Value = ""  'further
                    clear entry on that cell
                Next col_1

            Next row_1
        End If
    End If

    frm_FieldSpecify2.Show vbModeless

    With frm_FieldSpecify2
        .Top = 10
        .Left = Application.Width - frm_FieldSpecify2.Width - 30
    End With

End Sub

Public Sub GetBenchMark_Data(targetSht As String, DIV_COL As Long, SEGMENT_COL As Long,
 PROCESS_COL As Long, _
    Lower_Limit_COL As Long, Upper_Limit_COL As Long, _
    BENCHMARK_UNIT_COL As Long, BENCHMARK_UNIT_COLL As Collection)
    Dim n As Long

    Application.ScreenUpdating = False
    Application.Interactive = False

    Sheets(targetSht).Visible = True
    Sheets(targetSht).Select
```

```vb
    'Reset the content of a global variable (BenchMark_UL and LL Collection)
    For n = BenchMark_UL_List.Count To 1 Step -1
      BenchMark_UL_List.Remove (n)
    Next n
    For n = BenchMark_LL_List.Count To 1 Step -1
      BenchMark_LL_List.Remove (n)
    Next n

    For n = 2 To Rows.Count
      If IsEmpty(Cells(n, 1).Value) = True Then
        Exit For
      End If

      If Cells(n, DIV_COL).Value = DIV_SEL And _
            Cells(n, SEGMENT_COL).Value = SEG_SEL And _
            Cells(n, PROCESS_COL).Value = PROC_SEL Then

        On Error Resume Next

        BENCHMARK_UNIT_COLL.Add Cells(n, BENCHMARK_UNIT_COL).Value, CStr(Cells(n,
        BENCHMARK_UNIT_COL).Value)

        If Err.Number = 0 Then
          If Val(Cells(n, Upper_Limit_COL).Value) <= Val(Cells(n, Lower_Limit_COL).
          Value) Then
            BenchMark_UL_List.Add Cells(n, Upper_Limit_COL).Value
            BenchMark_LL_List.Add Cells(n, Upper_Limit_COL).Value
          Else
            BenchMark_UL_List.Add Cells(n, Upper_Limit_COL).Value
            BenchMark_LL_List.Add Cells(n, Lower_Limit_COL).Value
          End If
        Else
          Err.Clear
          On Error GoTo 0
        End If

      End If

    Next n

    Sheets(targetSht).Visible = xlSheetVeryHidden
    Application.ScreenUpdating = True
    Application.Interactive = True
End Sub

Public Sub GetUniqueEntries(targetSht As String, ColStart As Long, RowStart As Long,
retColl As Collection, Optional DIV_SELECTED As String = "" , _
      Optional DIV_COL As Long = 0, Optional SEGMENT_COL As Long = 0)

    Dim n As Long
    Dim empty_cell_cnt As Long
    Dim last_empty_cell_row As Long

    Application.ScreenUpdating = False
    Application.Interactive = False

    Sheets(targetSht).Visible = True
    Sheets(targetSht).Select

    For n = RowStart To Rows.Count
      If IsEmpty(Cells(n, 1).Value) = True Then
        Exit For
      End If

      On Error Resume Next

      If DIV_SELECTED = "thermo"  Then
        If InStr(LCase(Cells(n, 1).Value), "thermo" ) > 0 Then
          If DIV_COL > 0 Then
            If Cells(n, DIV_COL).Value = DIV_SEL Then
              If SEGMENT_COL > 0 Then
                If Cells(n, SEGMENT_COL).Value = SEG_SEL Then
                  retColl.Add Cells(n, ColStart).Value, CStr(Cells(n, ColStart).
                  Value)
                  If Err.Number > 0 Then
                    Err.Clear
                    On Error GoTo 0
                  End If
                End If
              Else
                retColl.Add Cells(n, ColStart).Value, CStr(Cells(n, ColStart).
                Value)
                If Err.Number > 0 Then
                  Err.Clear
                  On Error GoTo 0
                End If
              End If
            End If
          Else
            retColl.Add Cells(n, ColStart).Value, CStr(Cells(n, ColStart).Value)
            If Err.Number > 0 Then
              Err.Clear
              On Error GoTo 0
            End If
          End If
        End If
```

```
            Else
                If InStr(LCase(Cells(n, 1).Value), "thermo" ) = 0 Then

                    If DIV_COL > 0 Then
                        If Cells(n, DIV_COL).Value = DIV_SEL Then
                            If SEGMENT_COL > 0 Then
                                If Cells(n, SEGMENT_COL).Value = SEG_SEL Then
                                    retColl.Add Cells(n, ColStart).Value, CStr(Cells(n, ColStart).
                                    Value)
                                    If Err.Number > 0 Then
                                        Err.Clear
                                        On Error GoTo 0
                                    End If
                                End If
                            Else
                                retColl.Add Cells(n, ColStart).Value, CStr(Cells(n, ColStart).
                                Value)
                                If Err.Number > 0 Then
                                    Err.Clear
                                    On Error GoTo 0
                                End If
                            End If
                        End If
                    Else
                        retColl.Add Cells(n, ColStart).Value, CStr(Cells(n, ColStart).Value)
                        If Err.Number > 0 Then
                            Err.Clear
                            On Error GoTo 0
                        End If
                    End If
                End If
            End If

        Next n

        Sheets(targetSht).Visible = xlSheetVeryHidden

        Application.ScreenUpdating = True
        Application.Interactive = True

    End Sub

    '
    '
    Public Sub Show_Result()

        If DATA_VALIDATION = 1 Then
        Else
            MsgBox "You have not validated your data yet, please click on the Validate Entry
            tab ..." , vbCritical + vbOKOnly, "Err Msg"
        End If

        If DATA_VALIDATION = 1 Then
            Sheets("Benchmarking results" ).Visible = True
            'Sheets("Benchmarking results").Select

            Worksheets("Data input and Validation" ).Select

            If IsEmpty(Range("A12" ).Value) = True Or IsEmpty(Range("B11" ).Value) = True
            Then
                'If Range("B11").Value = "" Or Range("A12").Value = "" Then

                MsgBox "There doesn't seem to be complete data on this sheet ..."  & vbCrLf &
                _
                "Please ensure that cells A12 and B11 are not blank." , vbCritical + vbOKOnly,
                 "Critical checks"
                Exit Sub
            End If

            'Clean the characters and non-numbers

            Dim d As Range
            Dim kl As Range

            Application.ScreenUpdating = False

            Worksheets("Data input and Validation" ).Select
            Range("B12:U62" ).Select
            For Each kl In Range("B12:U62" )
                If kl.Value Like "*[!0-9,.,,,]*"  Or IsNumeric(kl.Value) = False Then
                    kl.Value = ""
                    kl.Interior.Color = vbWhite  'RGB(255, 0, 0)
                    kl.Font.Color = vbBlack
                End If
            Next
            Worksheets("Data input and Validation" ).Range("B12:U62" ).Select
            Selection.Interior.Color = vbWhite  'RGB(255, 0, 0)
            Selection.Font.Color = vbBlack
            Call UpdateList
        End If
    End Sub
```

```
Sub Validate_Sheet_click()
  Dim d As Range

  DATA_VALIDATION = 1
  Worksheets("Data input and Validation" ).Select
  Range("B12:U62" ).Select

  Selection.Interior.Color = vbWhite  'RGB(255, 0, 0)
  Selection.Font.Color = vbBlack

  For Each d In Range("B12:U62" )
    If d.Value Like "*[!0-9,.,,,]*"  Or IsNumeric(d.Value) = False Then '!pick all
the non-integers
      d.Interior.Color = vbRed  'RGB(255, 0, 0)
      d.Font.Color = RGB(255, 255, 0)
    End If
  Next

  Dim kl As Range

  MsgBox "Please note that only numbers and blank cells can be used for the
benchmarking exercise; where characters such as -_£%&><# etc and negative values
exist in the data, the wizard will replace same with blank cells highlighted in
Red" , vbCritical + vbOKOnly, "Critical checks"

  Worksheets("Data input and Validation" ).Select
  Range("B12:U62" ).Select
  For Each kl In Range("B12:U62" )
    If kl.Value Like "*[!0-9,.,,,]*"  Or IsNumeric(kl.Value) = False Then
      kl.Value = ""
    End If
  Next

End Sub
```

9.1.18 Mod_OTHER_Functions

Mod_OTHER_Functions VBAProject

```
Option Explicit

Private Sub Benchmarking_Results_Click()
  Call Show_Result

End Sub

Private Sub Benchmarking_Specifics_Click()
  frm_Benchmarking_Specifics.Show
End Sub

Private Sub Benchmarking_Start_Form_Click()
  frm_Benchmarking_Start_Form.Show
End Sub
'-----------------------------------------------------------------------------------------

'OTHER Functions
'i-Water Benchmarking Tool v 1.00
'Year: 2015
'-----------------------------------------------------------------------------------------

Sub cmdShowForm_click2()
  Dim FileNewName As String
  Dim Response As String

  Application.DisplayAlerts = False
  If ActiveWorkbook.Name = "i-Water Benchmarking Tool.xlsm"  Then
    Response = MsgBox("Please click OK to create a New Copy of this tool for your
analysis(es); otherwise, click Cancel to continue using this copy." , vbOKCancel
+ vbInformation, "Recommended" )

    Select Case Response
    Case 7
      GoTo Proceed
    Case 1
      GoTo SaveWithNewName
    End Select
```

```
        GoTo Proceed
        SaveWithNewName:

        FileNewName = (Left(ActiveWorkbook.Name, Len(ActiveWorkbook.Name) - 5)) & " (" &
         Format(Now(), "h mm AMPM, DD-MMM-YYYY" ) & ")" & ".xlsm" ' or Format(Now,
        "yyyy-mm-dd hh-mm-ss") & "_" & ActiveWorkbook & ") ".Name
        ActiveWorkbook.SaveAs ActiveWorkbook.Path & "\" & FileNewName

        MsgBox "The Original Copy is now successfully retained in its current location."
         & vbCrLf & "You are presently using the New Copy - See Title Bar for new name."
        , vbOKOnly + vbInformation, "Tool update"

    End If

    Proceed:
    Load frm_Application_Information

    frm_Application_Information.Show
    Application.DisplayAlerts = True
End Sub

Private Sub Contact_Information_Click()

    frm_Contact_Information.Show
End Sub

Private Sub Data_InputAndValidation_Click()
    Worksheets("Data input and Validation" ).Activate
    Range("a1" ).Select
End Sub

Sub Embedded_Charts_Name_Change()

    ActiveSheet.ChartObjects(2).Name = "Chart 2"

    ActiveChart.Parent.Name = "Chart 4"

End Sub

Private Sub Frm_Process_Assessment_Click()
    Frm_Process_Assessment.Show
End Sub

Private Sub GoTo_About_The_i_Water_Click()
    Sheets("About the i-Water Tool" ).Visible = xlVeryHidden
    Worksheets("About the i-Water Tool" ).Activate
    Range("a1" ).Select
    Sheets("Terms of Use" ).Visible = xlVeryHidden
End Sub

Private Sub GoTo_Terms_Of_Use_Click()
    Sheets("Terms of Use" ).Visible = xlVeryHidden
    Worksheets("Terms of Use" ).Activate
    Range("a1" ).Select
    Sheets("About the i-Water Tool" ).Visible = xlVeryHidden
End Sub

Sub Open_Heriot_Watt_Website_Click()
    On Error GoTo ErrHandler:

    Const Hyper As String = _
    "http://www.hw.ac.uk/"
    ThisWorkbook.FollowHyperlink Address:=Hyper

    ErrHandler:
    MsgBox "No internet connection!" & vbCrLf & _
    "Please ensure you are connected to the internet and try again. " , vbOKOnly +
    vbInformation, "Notification!"
    Exit Sub

End Sub

Sub Open_UKBCSD_Website_Click()

    On Error GoTo ErrHandler:

    Const Hyper As String = _
    "http://www.ukbcsd.org.uk/"
    ThisWorkbook.FollowHyperlink Address:=Hyper

    ErrHandler:
    MsgBox "No internet connection!" & vbCrLf & _
    "Please ensure you are connected to the internet and try again. " , vbOKOnly +
    vbInformation, "Notification!"
    Exit Sub

End Sub
```

```
Private Sub Print_Benchmarking_Results_Click()
   Dim Action As String

   Application.DisplayAlerts = False
   If Worksheets("Benchmarking Results" ).Range("Y1" ).Value = ""  Then
      Action = MsgBox("You have not completed the benchmarking assessment; please
      click OK to complete the last part of this exercise."  _
      & vbCrLf & "Skipping this stage, leaves you with a 5-page print preview
      including 3 blank pages. To skip same, click on the Cancel tab." , vbOKCancel +
      vbInformation, "Recommended" )

      Select Case Action
      Case 7
         GoTo Proceed
      Case 1
         GoTo CompleteBenchmarking
      End Select

      GoTo Proceed
      CompleteBenchmarking:
      Frm_Process_Assessment.Show
      Application.DisplayAlerts = True
      Exit Sub

      Proceed:
      ActiveWindow.SelectedSheets.PrintPreview
      Application.DisplayAlerts = True

   Else
      ActiveWindow.SelectedSheets.PrintPreview
   End If
End Sub


Sub Referring_To_About_the_iWater_Tool()
   Sheets("Terms of Use" ).Visible = xlVeryHidden
   Sheets("About the i-Water Tool" ).Visible = True
   Worksheets("About the i-Water Tool" ).Activate
   Range("a1" ).Select

End Sub

Sub Referring_To_Terms_of_Use()
   Sheets("About the i-Water Tool" ).Visible = xlVeryHidden
   Sheets("Terms of Use" ).Visible = True
   Worksheets("Terms of Use" ).Activate
   Range("a1" ).Select
End Sub

Sub Remove_Sec_Axis_from_Chart4()

   ActiveSheet.ChartObjects("Chart 4" ).Activate
   ActiveChart.SetElement (msoElementSecondaryValueAxisShow)
   ActiveChart.Axes(xlValue, xlSecondary).Select
'

'
   Selection.Delete
   ActiveSheet.ChartObjects("Chart 4" ).Activate
   ActiveChart.PlotArea.Select
   ActiveChart.SetElement (msoElementSecondaryCategoryAxisShow)
   ActiveChart.Axes(xlCategory, xlSecondary).Select
   Selection.TickLabelPosition = xlNone
   Selection.MajorTickMark = xlNone
   ActiveChart.Axes(xlCategory, xlSecondary).AxisBetweenCategories = False
   Selection.Format.Fill.Visible = msoFalse
   Selection.Format.Line.Visible = msoFalse
   Worksheets("Benchmarking Results" ).Range("A1" ).Select
End Sub
Private Sub Return_To_Home_Page_Click()
   Sheets("About the i-Water Tool" ).Visible = xlVeryHidden
   Sheets("Terms of Use" ).Visible = xlVeryHidden
   Worksheets("Home page" ).Activate
   Range("a1" ).Select
End Sub

Sub Unhide_Sheets()
   Sheets("Benchmarking Results" ).Visible = True
   Sheets("Data Input and Validation" ).Visible = True
   Sheets("Data Entry Sheet" ).Visible = True
   Sheets("Data Entry Sheet." ).Visible = True

End Sub
'
```

10.0 Appendix C

10.1 Application letter for research data collection

10/06/2014

Environment Agency
National Customer Contact Centre
PO Box 544
Rotherham
S60 1BY

Dear Sir/Madam,

DATA REQUEST FOR DOCTORAL RESEARCH

My name is Ajiero Ikenna; I am a PhD student currently conducting a research on *"Benchmarking and identification of best practices associated with industrial water in UK"*. One of the objectives of this research is to source comprehensive data on industrial water use in the UK, broken down in accordance with the Standard Industrial Classification (SIC) of economic activities. The dataset will be used for empirical analysis of how much water is consumed by the vast industrial subsectors in order to identify the water-intensive processes and corresponding water conservation opportunities.

The anticipated outcome of this work is the development of a benchmarking tool which aids resource efficiency and improves overall business competitiveness. This will have national impact as it offers the opportunity to compare the performance of UK operations across chosen industry sectors with respect to water usage and management, allowing operators to benchmark current performance, identify opportunities for improvement and implement the required changes.

Your detailed reports and published data on water use intensities in various industrial subsectors have been very revealing and indispensable to this research. It is on this note that I request that you please send me: Quantitative data on non-household water demand by SIC code (especially water use by the industrial sector), possibly covering: Food and Beverage, Chemicals, Metals production & transformation, thermo-electric generation, Pulp, paper & cardboard, etc. The study targets a 10-year data range (2003-2013); although, this will be eventually determined by the available data range. Accordingly, could you please send (if available): current industrial water use benchmarks? All collected data will be treated with utmost confidentiality and anonymity.

Hope this research further contributes to recent strategies on water use minimisation across the UK industrial sector, such as the Federation House Commitment towards achieving a 20% cut in water use in the food and drink sector by 2020.

Please find attached a copy of my school's permission to source this information.

Many thanks and hope to hear from you soon.

Best regards,

Ikenna R. Ajiero (email: ira30@hw.ac.uk; mobile: 07417582252)
PhD Student, Heriot Watt University

10.2 Approval to source data for PhD research

HERIOT WATT UNIVERSITY

05 June 2014

Dear Sir/Madam,

REQUEST TO RELEASE DATA FOR PHD RESEARCH

Student Name: Ajiero Ikenna Reginald
Course of Study: Doctor of Philosophy (Construction)
Method of Study: Full time on campus (Edinburgh)
School/Institute: Built Environment
Supervisors: Dr David Campbell and Prof Susan Roaf

Mr Ajiero has been granted approval by his supervisors to collect data for his PhD research on **'Benchmarking and identification of best practices associated with industrial water in UK'**, funded by the Business Council for Sustainable Development (BCSD-UK) in partnership with Heriot-Watt University.

Accordingly, the researcher has informed the school of his intention to request data from UK water and wastewater companies, the Environment Agency, SEPA, NIEA, DEFRA, WRAP, WaterWise, WRc, BERR, OFWAT, WIC, NIUR, industry trade bodies such as the Food & Drink Federation, Chemical Industries Association, Dairy UK, Scottish Whisky Association, companies covered under the SIC for manufacturing and other relevant sources.

Mr Ajiero has agreed to abide by the University Ethical Principles and the provision of Section 33 of the Data Protection Act - A practical note for researchers.

Your kind assistance towards providing the requisite data for his research will be highly appreciated.

Should you require any further information regarding the above, please contact the Research Team in the first instance on sbe-pgr-students@hw.ac.uk.

Yours faithfully

Colin Jones

Heriot-Watt University
Issued on behalf of the
05 JUN 2014
ACADEMIC REGISTRY
EDINBURGH, SCOTLAND, UK

Professor Colin Jones
Research Student Co-ordinator
Room WA 1.21
Email:- C.A.Jones@hw.ac.uk
Direct line: T +44(0)1314514628

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11.0 Appendix D

11.1 A Benchmarking Code of Conduct for Public Services

This code is based on *The Benchmarking Code of Conduct* originally devised by the American Productivity & Quality Center's International Benchmarking Clearing House and the US Strategic Planning Institute's Council on Benchmarking in the USA (CIPFA, 1996).

1.0 Legality
1.1 If there is any potential question on the legality of an activity, do not do it.
1.2 Avoid discussions or actions which could lead to, or imply, an interest in tender fixing, award of contracts, allocation of services, bribery, or any other anti-competitive or unlawful practice.
1.3 Do not discuss costs with a competitor if costs are an element of pricing.
1.4 Do not disclose anything arising from a benchmarking study to another organisation or individual without first obtaining permission from the other parties involved in the benchmarking.
2.0 Exchange
2.1 Be willing to provide the same type and level of information that you request from your benchmarking partner to your benchmarking partner.
2.2 Communicate fully at an early stage to clarify expectations, avoid misunderstanding and establish mutual interest in the benchmarking exchange.
2.3 Be honest.
3.0 Confidentiality
3.1 Treat all information obtained through benchmarking as confidential to the individuals and organisations involved.
3.2 An organisation's participation in a study is confidential and should not be divulged to anyone else without their permission.
4.0 Use
4.1 Use information obtained through benchmarking only for improving organisational performance.
4.2 The use or communication of a benchmarking partner's name with any data obtained or practices observed requires the prior permission of that partner.
4.3 Do not use any benchmarking information to promote your own services.
5.0 First Party Contact
5.1 Initiate benchmarking contacts through the appropriate person designated by the organisation, if at all possible.
5.2 Respect the culture and ways of working in your partner organisations, and work within mutually agreed procedures.
6.0 Third Party Contact
6.1 Obtain an individual's permission before providing his or her name in response to a contact request.
6.2 Do not mention a contact's name in an open forum without the contact's prior permission.
7.0 Preparation
7.1 Demonstrate commitment to the benchmarking process by being prepared before making an initial contact.
7.2 Make the most of your partner's time by being fully prepared for each exchange of information.
7.3 Help your benchmarking partner to prepare by providing them with a questionnaire and agenda before benchmarking visits.
8.0 Completion
8.1 Follow up each commitment made to your benchmarking partner promptly.
8.2 Complete each benchmarking study to the satisfaction of all benchmarking partners as mutually agreed.
9.0 Understanding and Action
9.1 Understand how your benchmarking partner would like to be treated and treat them in that way.
9.2 Understand how your benchmarking partner would like to have their information handled and used, and handle and use it in that manner.

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